Addis Ababa Science and Technology University
School of Civil Engineering and Construction Technology

# COMPARISON OF WOOD ASH AND BAGASSE ASH SOIL STABILIZATION METHODS

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**CERTIFICATION**

The thesis titled "COMPARISON OF WOOD ASH AND BAGASSE ASH SOIL STABILIZATION METHODS"

"by Melat Nesru meets the regulations governing the award of the degree of Master of Engineering (M.Eng) in Geotechnical Engineering in Addis Ababa Science and Technology University and is approved for its contribution to knowledge and literary presentation.

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| | |
|---|---|
| AASHTO | American Association of Highway and Transportation Officials |
| ASTM | American Society for Testing and Materials |
| BA | Bagasse ash |
| BS | British Standard |
| CAH | Calcium aluminate hydrate |
| CEC | Cation Exchange Capacity |
| CBR | California Bearing Ratio |
| CSH | Calcium Silicate Hydrate |
| ERA | Ethiopian Roads Authority |
| FSI | Free swell index |
| FSR | Free swell ratio |
| GSA | Groundnut shell ash |
| IS | Indian Standard |
| LL | Liquid Limit |
| PL | Plastic Limit |
| MDD | Maximum Dry Density |
| OMC | Optimum Moisture Content |
| PI | Plastic Index |
| PL | Plastic Limit |
| RHA | Rise husk ash |
| SCBA | Sugarcane bagasse ash |
| SP | Swelling pressure |
| UCS | Unconfined compressive strength |
| USA | United States of America |

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## ABSTRACT

With the increasing of population and the reduction of available land, more and more construction of buildings and other civil engineering structures have to be carried out on weak or soft soil. Owing to such soil of poor shear strength and high swelling & shrinkage, a great diversity of ground improvement techniques such as soil stabilization and reinforcement are employed to improve mechanical behavior of soil, thereby enhancing the reliability of construction. Expansive soil is one of the major soil deposits of Ethiopia. They exhibit high swelling and shrinking when exposed to changes in moisture content and hence have been found to be most troublesome from engineering considerations. Stabilization occurs when lime is added to expansive soil and a pozzolanic reaction takes place. The hydrated lime reacts with the clay particles and permanently transforms them into a strong cementations matrix. Expansive soil showing low to medium swelling potential from Addis Ababa was used for determining the basic properties of the soil. Changes in various soil properties such as Liquid limit, Plastic Limit, Maximum Dry Density, Optimum Moisture Content, and California Bearing Ratio were studied.

Expansive Soil is a kind of high plastic clay. Because it has Strong hydrophilic mineral composition, its engineering prosperities embodies that its shape contracts under dehydrating, Inflation and softening under the influence of water and the strength attenuates. This is very difficult to construct in the region of expansive soil. In the region of seasonal frozen, as capillary water rising height is larger; it is prone to phenomenon of frost boil or thawing settlement. It has important meaning to improve hydrophilic and physical and mechanical properties of expansive soil for Slope stability of embankment and cutting of highway engineering and reducing the cost of investment. The paper discusses the engineering properties of expansive soil in Detail; expound some main methods of improving expansive soil with wood ash and bagasse ash, compare and analysis the mechanism and characteristics of the methods. The paper introduces preliminary testing methods of Expansive soil performance and prospects improved in the future.

# CHAPTER ONE

# INTRODUCTION

## 1.1 General description

Expansive soil, which is known for its volume change upon exposure to moisture fluctuation, causing number of problems in most structures built in Addis Ababa as well as in Ethiopia. Recent researches in assessing the failures caused on structures built on expansive soils showed that more than 60% of the structures are damaged due to causes associated with expansive soils.

Therefore we need to direct some remarks to the problems regarding to these expansive soils. Expansive soils occur in many parts of Ethiopia but particularly in arid and semi-arid regions. In these regions, evaporation rates are higher than the annual rainfall so that there is almost always a moisture fluctuation in the soil. The addition of water will cause ground heave in soils possessing swelling potential. The ground heave that results from soil swelling potential is a multi-factorial phenomenon that involves a combination of the type of material, type and amount of clay minerals, initial moisture content, and initial dry density.

Stabilization has the potential to reduce initial construction cost, time and quality through improved sub grade stability and reductions in pavement structure.

The concept of stabilization started 5000 years ago. McDowell (1959) stabilized earth roads were used in ancient Mesopotamia and Egypt, and that the Greek and the Romans used soil-lime mixtures. Kézdi (1979) mentioned that the first experiments on soil stabilization were achieved in the USA with sand/clay mixtures around 1906. In the 20th century, especially in the thirties, the soil stabilization relevant to road construction was applied in Europe.

In Germany, Vosteen (1998 & 1999) use of cement or lime for the stabilization of pavement bases (during the past few decades) was investigated and developed into practical construction procedures. These practical procedures have been improved and covered periodically by the technical standards for road and traffic. Fly ash-soil stabilization for road construction is applied in USA, Japan, Scandinavian countries, and some other countries like India. The Engineers are often faced with the problem of constructing roadbeds on or with soils expansive soils. These problematic soils do not possess enough strength to support the wheel loads upon them either in construction or during the service life of the pavement. These soils must be, therefore, treated to provide a stable sub-grade or a working platform for the construction of the pavement. One of the strategies to achieve this is soil stabilization The soil stabilization includes both physical stabilization [such as dynamic compaction] and chemical stabilization [such as mixing with cement, fly ash, lime, and lime by-Products, etc ] (Materials & Tests Division, Geotechnical Section, Indiana, (2002).

Geotechnical properties of controversial soils like expansive soils are enhanced by different techniques. The problematic soil is removed and replaced by a better quality material or treated using mechanical and/or chemical stabilization.

Different methods have been conducted to enhance and treat the geotechnical properties of the Expansive soils (such as strength and the stiffness) by treating it in situ. These methods include densifying treatments (such as compaction or preloading), pour water pressure reduction techniques (such as dewatering or electro-osmosis), the bonding of soil particles (by ground freezing, grouting, and chemical stabilization), and use of reinforcing elements (such as geo textiles and stone columns) (William Powrie, 1997).

The chemical stabilization of the expansive soils is very important for many of the geotechnical engineering applications such as pavement structures, roadways, building foundations, channel and reservoir linings, irrigation systems, water lines, and sewer lines to avoid the damage due to the settlement of the soft soil or to the heave of the expansive soils.

## 1.2 Statement of the Problem

Failure of structures built on expansive soils is phenomena, which take place mainly due to moisture content Fluctuation. In Ethiopia where this problems are significantly visible measures should be taken considering the quality, cost and time consumption of the remedial action which appears to be stabilization.
The need to address the alarmingly increasing cost of soil stabilizers has led to intense research towards cost effective utilization of wastes for engineering purposes. This Project is to investigate the best ways to make problematic (Expansive) soils useful (better) for geotechnical engineering purposes and requirements for engineering needs.

The basic problems which enforce to do this paper are:

- Foundation failure of the structures due presence of expansive soils
- Cost savings, because wood ash is by far cheaper than traditional stabilizers such as cement and lime
- Low bearing capacity of expansive clays
- High cost of replacement with selected Materials of the expansive soils.
- Use of west products of fuel wood and pulp products for any other purpose
- The production of traditional stabilizers, such as cement and lime, is environmental unfriendly processes;
- Waste management can be done economically;

## 1.3 Objectives of the Research

### General Objective

The general objective of this study is to evaluate the best choice in quality, cost and time as a stabilizing agent for expansive soil between Wood ash and bagasse ash stabilization techniques. This is achieved through the following specific objectives:

### Specific Objectives

The specific objectives of this study are:

1. To evaluate the effect of wood ash on the properties of the expansive soil using Atterberg limits, free swell, free swell index, free swell ratio, compaction and CBR.
2. To compare the changes in properties of expansive soil treated with wood ash with bagasse ash stabilized soil.

## 1.4 Research Methodology

In order to achieve the objectives of this study the following methodologies were adopted:

**i)** Literature survey: different types of literatures; such as text books, academic journals, and research papers pertaining to expansive soil, and different soil stabilization techniques were reviewed.

**ii)** Analysis and discussion of test results: based on the theories and laboratory test results, the results obtained have been analyzed and discussed thoroughly.

**iii)** Compare and contrast the economic aspect of wood ash with bagasse ash stabilizer and analyze environmental effects.

**iv)** Formulation of conclusions and recommendations based on the results obtained.

**v)** Finally compiling and writing of the paper work.

### 1.5 Scope of the Study

This study has been supported by different types of literatures and a series of case studies. However, the findings of the research are limited to two soil sample considered in this research which is expansive clay soils. The results are also specific to the type of additives used and test procedures that have been adopted in the experimental work. Therefore, findings should be considered indicative rather than definitive for filed applications.

### 1.6 Structure of the Research

The presentation of this thesis is organized in Five Chapters. The first Chapter gives a brief description of the thesis introduction, objectives, scope and methodology employed. Chapter two and Chapter three presents conceptual background on expansive soils and soil stabilization respectively. Important details from soil stabilization are included in Chapter three. The fourth Chapter briefly describes the soil stabilization done using wood ash and bagasse ash in Ethiopia. The fifth Chapter presents the conclusion and comparison of results with different aspects.

# CHAPTER TWO

# REVIEW ON EXPANSIVE SOIL

## 2.1 INTRODUCTION

Expansive soils other local terms are used to describe these soils in many areas such as “regur” soils in India, “margalitic” soils in Indonesia and “black turfs” in Africa *“tirs”* in Morocco. With the new soil taxonomy system these soils are referred as “vertisols”.

Scientifically speaking expansive soil is a type of clay that is known as a lightweight aggregate with a rounded structure, with a porous inner, and a resistant and hard outer layer.

It is a clay or soil that is prone to large volume changes (swelling and shrinking) that are directly related to changes in water content. Soils with a high content of expansive minerals can form deep cracks in drier seasons or years; such soils are called vertisols. Soils with smectite clay minerals, including montmorillonite and bentonite, have the most dramatic shrink-swell capacity.

The mineral make-up of this type of soil is responsible for the moisture retaining capabilities. All clays consist of mineral sheets packaged into layers, and can be classified as either 1:1 or 2:1. These ratios refer to the proportion of tetrahedral sheets to octahedral sheets. Octahedral sheets are sandwiched between two tetrahedral sheets in 2:1 clays, while 1:1 clays have sheets in matched pairs. Expansive clays have an expanding crystal lattice in a 2:1 ratio; however, there are 2:1 non-expansive clays.

Mitigation of the effects of expansive clay on structures built in areas with expansive clays is a major challenge in geotechnical engineering. Some areas mitigate foundation cracking by watering around the foundation with a soaker hose during dry conditions. This process can be automated by a timer, or using a soil moisture sensor controller. Even though irrigation is expensive, the cost is small compared to repairing a cracked foundation. Another important characteristic of the expansive clay is its vulnerability to physical changes, according to the amount of water. For example, in a wet season, the clay has the capacity of swelling, and on a dry season, it can shrink and form cracks. According to Biswas and Kriscna, “there are several types of clay minerals of which Montmorillonite has the maximum swelling potential”.

## 2.2 The formation of Expansive soils with respect to soil forming factors

The expanded clay is obtained by heating of different types of clay, at a temperature of approximately 1200 °C, using a rotary kiln.

It was first thought that Expansive soils occur only in monsoonal type of climates with distinct annual wet and dry seasons in the tropics and subtropics, because of earlier recognition of their associations with these climates. However, they are now known to occur in almost every major climatic zone of the world and their classification has developed (Ahmed 1996). Annual rainfall between 300-900mm per year favors the formation of the soils (Katti et. al., 2002), however, higher rainfall values of 1270mm/year have also been recorded.
Black cotton soils have been identified on igneous, sedimentary and metamorphic rocks. They are formed mainly by the chemical weathering of mafic (basic) igneous rocks such as basalt, norite,

andesites, diabases, dolerites, gabbros and volcanic rocks and their metamorphic derivatives (e.g. gneisses) which are made up calcium rich feldspars and dark minerals which are high in the weathering order, in poorly drained areas with well-defined wet and dry seasons. All constituents weather to form amorphous hydrous oxides and under suitable conditions clay minerals develop. The absence of quartz leads to the formation of fine grained, mostly clay size, plastic soils which are highly impermeable and easily becomes waterlogged. In addition abundant magnesium and calcium present in the rock adds to the possibility of formation of black cotton soil with its attendant swelling problem (Ola, 1983). The black cotton soils have also formed over sedimentary materials such as shales, limestone, slates etc.

Ahmad (1983) found that although the parent materials are diverse, one striking feature which is common to all is the fact that the parent materials are rich in feldspar and ferromagnesian minerals which yield clay residue on weathering. He also noted that where the parent rock is not mafic (basic), alkali earth elements can be added through seepage or by flooding waters.

Katti et al., (2002) black cotton soil deposits are formed under conditions where the slope of the terrain is less than $3^{o}$

The most frequent physiographic position of Expansive soils is flat, alluvial plains (Dudal and Eswaran,1988; Eswaran et al., 1988) such as those found in Sudan, Texas in the USA, Darling Downs in Australia, the Accra plains, Ho-Keta plains and the Winneba plains in Ghana (USAID/BRRI, 1971; Building and Road Research Institute, 1985). Other fewer occurrences are the Lufina valley of Zaire, the Kafue Flats of Zambia and the Panamalenga plains and the Springbok flats in Botswana, and South Africa respectively. However, E#xpansive soils also occur in surfaces with greater slopes (Ahmad, 1983).

Clemente et al., (1996) reported that time of formation of vertisols are usually inferred from the age of the underlying parent material from which the soil has developed. Furthermore, they realized that most vertisols are derived from cenozoic era materials including Tertiary and Quaternary.

## 2.3 Clay mineralogy

The three most common types of clay minerals are Montmorillonite, Illite, and Kaolinite.

### 2.3.1 Montmorillonite

Montmorillonite is the most common of all the clay minerals and is well known for its swelling properties. Its basic structure consists of an alumina sheet sandwiched between two silica sheets and is symbolically represented as shown in Fig 2.1a.

The basic montmorillonite units are stacked one on top of the other (as shown in fig 2.1b), but the bond between the individual units is relatively weak and water is easily able to penetrate between the sheets and cause their separation and hence swelling. Therefore, montmorillonite has very high degree of expansiveness.

### 2.3.2 Illite

Illite has a basic structure similar to that of montmorillonite (fig 2.1a). However, the basic illite units are bonded together by potassium ions which are non-exchangeable (fig 2.1b). Because of this, the illite units are reasonably stable and so that mineral swells much less than montmorillonite. Hence, illite has moderate degree of expansiveness.

### 2.3.3 Kaolinite

Kaolinite has a structural unit made up of alumina sheets joined to silica sheet and is symbolized as indicated in Fig 2.1a. Kaolinite consists of many such layers stacked one on top of the other as shown in Fig 2.1b.

The bond that exists between layers is tight and hence it is difficult to separate the layers. As a result kaolinite is relatively stable and water is unable to penetrate between the layers. Consequently kaolinite has low degree of expansiveness.

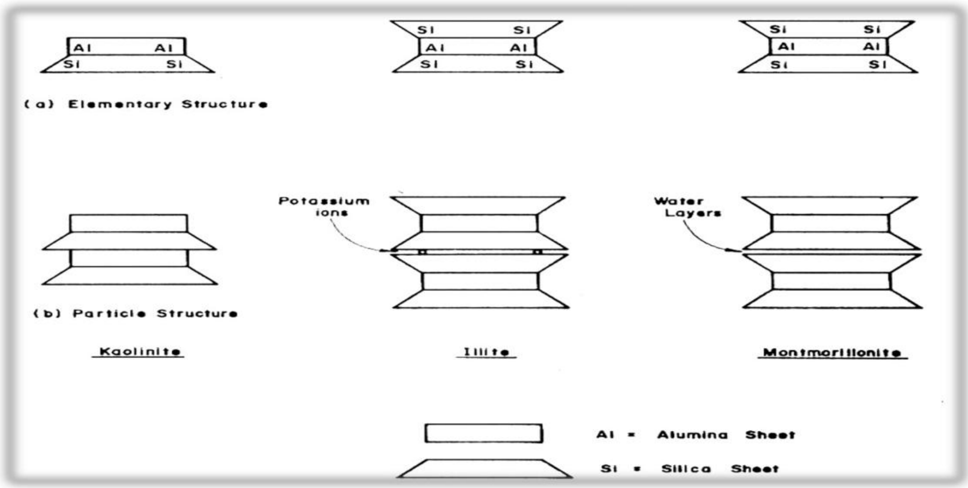


*Figure 2.1 Symbolic representation of clay minerals structure.*

## 2.4 Distribution of black cotton soils

### 2.3.1 Worldwide distribution of black cotton (expansive) soils

Expansive soils (vertisols) have been reported all over the world and have been found to occupy about 2% (257 million hectares) of the total ice-free land area of the earth with 72million hectares occurring in India, 71million hectares in Australia (Swindale, 1988) and 43million hectares is in Africa(Virmani, 1988). Countries reported to have expansive soils are Australia (Aitchison, et. al., 1962; Ingles and Metcalf, 1972), Algeria (Afes and Didier, 2000), Botswana, Ethiopia (Mgangira and Paige-Green, 2008), Bulgaria, Hungry, Italy (Dudal and Eswaran, 1985), Togo (Oscar et al.,1977), Nigeria (Ola, 1976, 1983; Osinubi, 2006), South Africa (Van Der Merwe, 1964), Morocco, Chad, Cameroon,Kenya, Zambia, (USAID/BRRI, 1971), Tanzania (Bucher and Sailie, 1984), Sudan (Charlie et al., 1984), India (Michael, 2006; Rao et al., 2001), Ghana (Building and Road Research Institute, 1985; USAID/BRRI, 1971) etc. Figure 2.2 shows the major distribution of black cotton soils in the world.

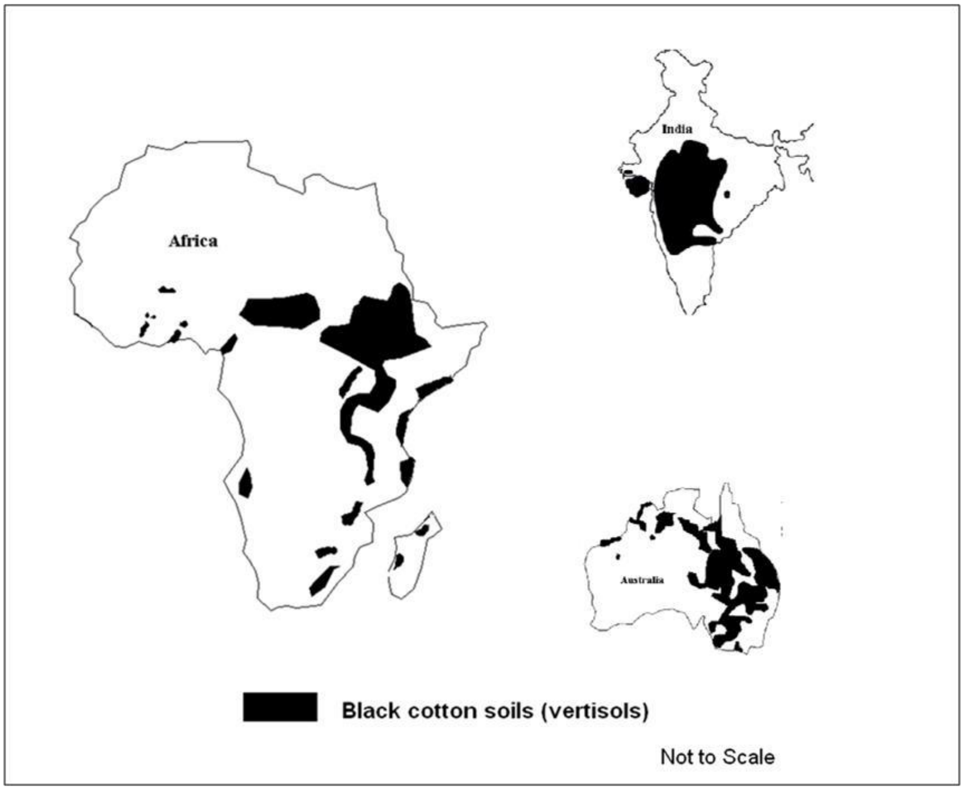


*Fig 2.2. Distribution of expansive soils (Vertisols) with special reference to areas of major concentrations (redrawn from Swindale, 1988, USAID/BRRI, 1971 and Soils and Land Resource Division, USA (undated)*

### 2.3.2. Distribution of black cotton expansive soils in Ethiopia

The aerial coverage of expansive soils in Ethiopia is estimated to be 24.7 million acres (Lyon associates, 1971; as cited by Nebro, D., 2002).

Expansive soil is known to be widely spread in Ethiopia. Although the extent and range of distribution of this problematic soil has not been studied thoroughly. The southern, south-east and south-west part of the city of Addis Ababa areas, where most of the recent construction are being carried out and central part of Ethiopia following the major trunk roads like Addis-Ambo, Addis-Woliso, Addis-Debre Birhan, Addis-Gohatsion-Debre Markos, Addis-Modjo are covered by expansive soils; areas like Mekele and Gambella are covered by expansive soils.

*Fig 2.3: Distribution of expansive soil in Ethiopia (Tilahun, D., 2004; Teklu, D., 2003)*

| **Country** | **Total area Covered(Million Hectares)** | **Area Covered (%)** |
|---|---|---|
| Australia | 70.5 | 28 |
| India | 60 | 24 |
| Sudan | 40 | 16 |
| Chad | 16.5 | 7 |
| Ethiopia | 10 | 4 |

*Table 2.1 Distribution of Black Cotton Soil*

From this table it is clear that these countries are the main regions covering with this soil. The total area covered by expansive soil is 250 million hectares and Australia, India, Sudan, Chad and Ethiopia contain more than 80% of total area of world.

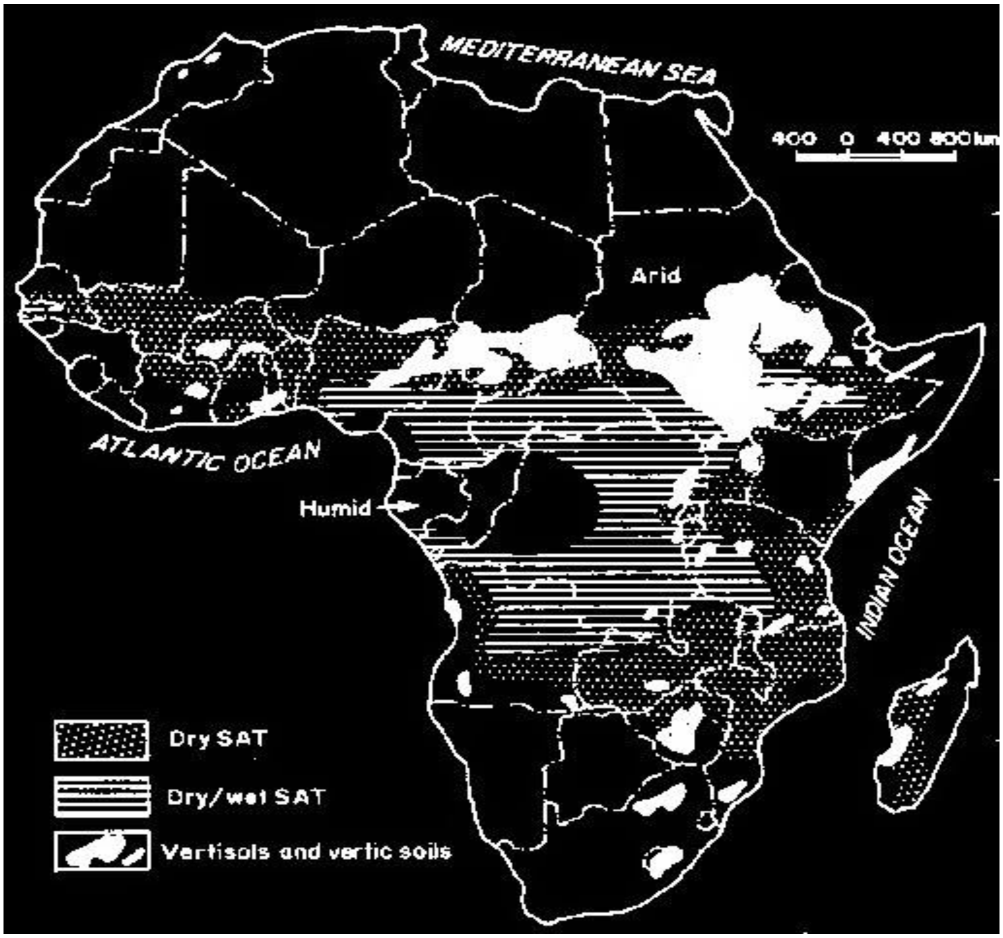


*Fig 2.4: Area covering Ethiopia Plateau and Rift valley*

## 2.4 Identification of expansive soils

Identification of potential swelling or shrinking subsoil problems is an important tool for selection of appropriate design and methods of construction (Van Der Merwe, 1964 and Hamilton, 1977).
Despite the lack of standard definition of swell potential (Nelson and Miller, 1992), there exist various geotechnical methods to identify the swelling potential of soils. Surface examination, geological and geomorphologic description can give indicators of expansive soils. The initial identification in this study places the emphasis on recognizing and establishing the identity and individuality of soils by visual and manual methods. However, identification is not just restricted to the visual present precursors of expansive soils, but also to the careful review of formation history of the grains. Generally, the soil textures are a result of geological history, soil composition and sedimentation, local climatic conditions, precipitation and the hydrological condition, pH etc.

The morphological description includes a host of many things such as ground water table situation, color of the soil, soil consistence, soil texture, soil structure, texture groups etc. Most of the relevant physical and mechanical properties to give indicators of swell potential are obtained by performing geotechnical index property tests such as Atterberg limits, unit weights and grain size distribution. Other tests to determine the swell potential include volume change tests (free swell and swell in oedometer test), coefficient of linear extensibility (COLE), and mineralogical compositions by x-ray diffraction (XRD) test and total suction test.

The geotechnical methods of identification of expansive soils can be broadly divided into direct methods and indirect methods. The direct methods consist essentially of laboratory swelling tests (swell percent and swell pressure) while indirect methods base on the correlation of measured soil properties with swell percent or swell pressure by empirical or semi-empirical mathematical expressions or graphical comparisons. The indirect approaches rely on empirical correlation between geotechnical properties like moisture content, Atterberg's limits, colloids etc. and swell index.

### 2.4.1 Visual identification

An estimation of shrink-swell potential can be made by observing the extent of desiccation cracks (Figure 2.5), popcorn (Figure 2.6), rill and gully erosion and surface textures of the soil (Lucian et al., 2006)1. The development of desiccation cracks in the sun-parched ground surface rich in expansive clay deposits is apparent during the dry periods (Day, 1999). These cracks act as planes of weakness within the soil mass and cause reductions in the overall strength and stability of the soil. The degree of potential swell determines the size of the cracks (Mitchell, J.K., 1993).

Great potential swell is indicated by large and more frequent polygon arrangements of cracks while the network of small and thin cracks indicates low shrink/swell. Soils containing expansive clays become very sticky and plastic when wet and adhere to soles of shoes or tires of vehicles.

They are also relative easy to roll into small threads. Moreover, the soils that are very plastic and weak when wet will be almost rocky-hard when dry during dry weather.

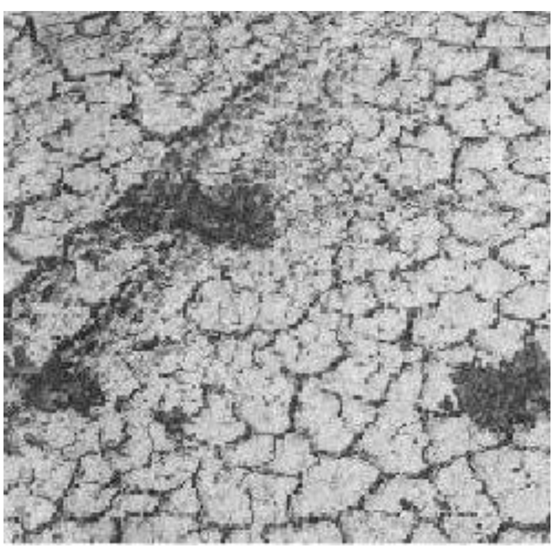

*Fig 2.5: Expansive soil showing cracks*

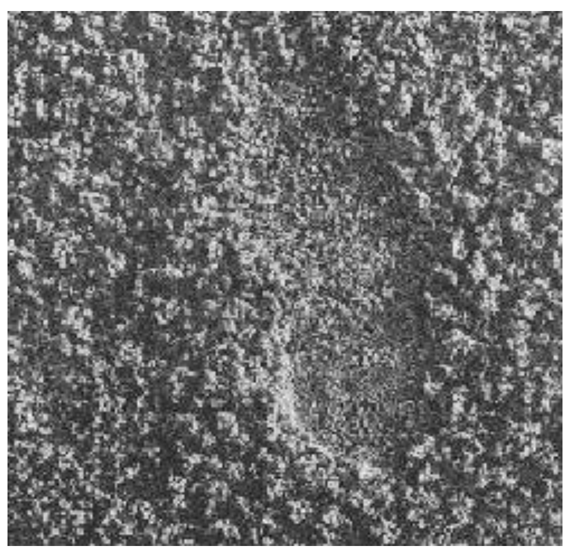

*Fig 2.6 Expansive soil showing popcorn*

### 2.4.2 Geological identification

Geology provides good information about the method of forming a mass into size, shape and behaviour (Lambe and Whitman, 1996). Good well-documented geological information will facilitate quick decision for the selection of relevant methods and the extent of geotechnical site investigations. It is the base to judge the efficacy of the test methods and assess the validity of the results.

Geological description is usually obtained by the study of the site history and geological maps. Information on the maps can give valuable idea of the soil composition as the preliminary information for further investigations.

### 2.4.3 Geomorphologic identification

The presence of free water at a particular depth as well as its seasonal variation in the soil has strong effect on the swelling potential of the soil. The water holding capacity or moisture content of soil in particular, provides a rough indicator of the soil's compressibility, strength and swelling potential characteristics. The benefit of proper prediction of trends in the groundwater table and fluctuations in soil moisture content cannot be overemphasized in establishing their effects on the potential expansion characteristics of soils.

### 2.4.5 Field Identification

Soils that can exhibit high swelling potential can be identified by field observations, mainly during reconnaissance and preliminary investigation stages. Important observations include (Chen, F.H., 1988; Nelson, D.J., and Miller, J.D., 1992):

- Usually have a color of black or grey.
- Wide or deep shrinkage cracks.
- High dry strength and low wet strength.
- Stickiness and low trafficability when wet.
- Cut surfaces have a shiny appearance.
- Appearance of cracks in nearby structures.

### 2.4.6 Laboratory Identification

Laboratory identification of expansive soils can be categorized into mineralogical, indirect and direct methods.

### 2.4.7 Mineralogical Identification

Clay mineralogy is a fundamental factor controlling expansive soil behavior. Clay minerals can be identified using a variety of techniques. The techniques that can be used are (Chen, F.H., 1988; Nelson, D.J. and Miller, J.D., 1992):

- X-ray diffraction
- Differential thermal analysis
- Dye adsorption
- Chemical analysis
- Electron microscope resolution

But these methods are not suitable for routine tests because of the following reason;

- They are time consuming;
- They require expensive test equipment; and

- The results can only interpreted by specially trained technicians.

### 2.4.8 Indirect Methods

In this method simple soil property tests can be used for the evaluation of swelling potential of expansive soils. Such tests are easy to perform and should be included as routine tests in the investigation of expansive soils. Such tests may include (Chen, F.H., 1988; Nelson, D.J. and Miller, J.D., 1992):

#### *i. Atterberg Limits*

In this method, measurement of the atterberg limit of the soil is conducted for identification of all soil and provides a wide acceptable means of rating, especially when they are combined with other tests they can be used to classify expansive soils.

The water content at which the soil changes from one state to other state are known as consistency limits or Atterberg"s limit .The Atterberg"s limit which are useful for engineering purposes are; Liquid limit, plastic limit and shrinkage limit. These limits are expressed as percent water content.

| **Swelling potential** | **Plasticity index** |
|---|---|
| Low | 0-15 |
| Medium | 10-35 |
| High | 20-55 |
| Very high | 35 and above |

*Table 2.2: Relation between the swelling potential of clays and the plasticity index*

#### *ii. Free Swell Tests*

The free swell test may be considered as a measurement of volume change in clay upon saturation and is one of the most commonly used simple tests to estimate the swelling potential of expansive clay. Experiments indicated that a good grade of high swelling commercial bentonite will have a free swell of from 1200 to 2000 percent. Soils having a free swell value as low as 100 percent can cause considerable damage to lightly loaded structures, and soils having a free swell value below 50 percent seldom exhibit appreciable volume change even under very light loadings. The free swell percentage can be computed using Equation (2.1) from the relationship between initial and swelled volume. (Chen, F.H., 1988; Nelson, D.J., and Miller, J.D., 1992; Teferra, A., and Leikun, M., 1999)

$$FS = \frac{V - V_o}{V_o} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

Where: FS = free swell, %

V = soil volume after swelling, cm3

$V_o$ = volume of dry soil, 10cm3

### *iii. Free Swell Index*

Free swell index is also one of the most commonly used simple tests to estimate the swelling potential of expansive clay. The procedure involves in taking two oven dried soil samples passing through 425µm sieve, 10cc each were placed separately in two 100ml graduated soil sample. Distilled water was filled in one cylinder and kerosene in the other cylinder up to 100ml mark. The final volume of soil is computed after 24hours to calculate free swell index. The free swell index is then calculated using Equation (2.2). (Amer, A., and Mattheus, F.A., 2006)

$$\text{Free Swell Index} = \frac{V_w - V_k}{V_k} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

$V_w$ = Final volume in Water

$V_k$ = Final Volume in Kerosene

| **Free swell Index (%)** | **Degree of Expansion** |
|---|---|
| Less than 20 | Low |
| 20 to 35 | Moderate |
| 35 to 50 | High |

| | |
|---|---|
| Greater than 50 | Very high |

*Table 2.3: Degree of expansion and differential free swell index (Ranjan, G., and Rao,A.S.R., 2002)*

### iv. Atterberg limits tests

In this method, measurement of the plasticity and the shrinkage characteristics of the soil are conducted for identification of all engineering soils and provide a wide acceptable means of rating. Especially when they are combined with other tests they can be used to classify expansive soils. The different types of limits under this method are Liquid limit, Plastic limit and Shrinkage

Holtz and Gibbs (1956) demonstrated that the plasticity index, Ip, and the liquid limit, LL are useful indices for determining the swelling characteristics of most clays. Since the liquid limit and the swelling of clays both depend on the amount of water clay tries to absorb, it is natural that they are related. The relation between the swelling potential of clays and the plasticity index has been established.

### v. Colloid content tests

This test is used to determine the quantity of material in a soil sample that is smaller than a selected size, expressed as a percentage by weight of the total sample. Sizes used are 2μm (0.002mm) and 1μm (0.001mm); the upper limit of the clay range is generally considered to be 2 to 5 μm. The test usually requires hydrometer analysis. There is a direct relationship between colloid content and swelling potential; (Chen, 1988). For a given clay type, the amount of swell will increase with the amount of clay present in the soil.

### vi. Cation exchange capacity

Researchers like Chen, 1988 have established thresholds of some chemical properties of soils for instance cation exchange (CIE) of different clay types, and established relationship with soil expansion potential.

| Clay mineral | CIE(meq/100g) | Expansion potential |
|---|---|---|
| Kaolinite | 3-5 | Low |
| Illite | 10-40 | Moderate |
| Montmorillonite | 60-100 | High |

*Table.2.4. Rate of CIE capacity of clay minerals and the respective expansion potential that they exhibit (Bell;Chen, 1988).*

### 2.4.9 Direct methods of identification of expansive soils

These identification methods offer the most useful data by direct measurement; and tests are simple to perform and do not require complicated equipment. Testing should be performed on a number of samples to avoid erroneous conclusions. Direct measurement of expansive soils can be achieved by the use of conventional one-dimensional consolidometer.

## 2.5 General classification of expansive soils

### 2.5.1 AASHTO SOIL CLASSIFICATION SYSTEM

The American Association of State High Way transport officials (AASHTO) classification system usually used for high way construction. This system of classification takes into account grain size, liquid limit and plasticity characteristics of soils. According to this system, soil is classified into seven major groups from A-1 through A-7.

| General classification | Granular materials (35% or less of total sample passing No. 200 sieve) | | | | | | |
|---|---|---|---|---|---|---|---|
| Group classification | A-1 | | A-3 | A-2 | | | |
| | A-1-a | A-1-b | | A-2-4 | A-2-5 | A-2-6 | A-2-7 |
| Sieve analysis (% passing) | | | | | | | |
| No. 10 sieve | 50 max | | | | | | |
| No. 40 sieve | 30 max | 50 max | 51 min | | | | |
| No. 200 sieve | 15 max | 25 max | 10 max | 35 max | 35 max | 35 max | 35 max |
| For fraction passing No. 40 sieve | | | | | | | |
| Liquid limit (LL) | | | | 40 max | 41 min | 40 max | 41 min |
| Plasticity index (PI) | 6 max | | Nonplastic | 10 max | 10 max | 11 min | 11 min |
| Usual type of material | Stone fragments, gravel, and sand | | Fine sand | Silty or clayey gravel and sand | | | |
| Subgrade rating | | | | Excellent to good | | | |

| General classification | Silt–clay materials (More than 35% of total sample passing No. 200 sieve) | | | |
|---|---|---|---|---|
| Group classification | A-4 | A-5 | A-6 | A-7<br>A-7-5[a]<br>A-7-6[b] |
| Sieve analysis (% passing) | | | | |
| No. 10 sieve | | | | |
| No. 40 sieve | | | | |
| No. 200 sieve | 36 min | 36 min | 36 min | 36 min |
| For fraction passing No. 40 sieve | | | | |
| Liquid limit (LL) | 40 max | 41 min | 40 max | 41 min |
| Plasticity index (PI) | 10 max | 10 max | 11 min | 11 min |
| Usual types of material | Mostly silty soils | | Mostly clayey soils | |
| Subgrade rating | Fair to poor | | | |

[a] If PI ≤ LL − 30, the classification is A-7-5.
[b] If PI > LL − 30, the classification is A-7-6.

### 2.5.2 Unified soil classification System

This system of classification is originally developed by A. Casagrande in 1942 and later revised and adopted by the United States bureau of reclamation and the US army crops engineers in 1952. In this classification system a correlation is made between swell potential and unified soil classification as follows. The system has also been adopted by the American society of testing materials (ASTEM). This method used to classify soils for general purpose based on the particle size analysis and their plasticity characteristics.

# CHAPTER THREE

# REVIEW ON SOIL STABILIZATION

## 3.1 INTRODUCTION

The practice of stabilizing soils dates back to the age of the Romans. Other nations such as the United States and China among many others adopted it in the latter half of the 20th century. In the past, soil stabilization was done by utilizing the binding properties of clay soils, cement-based products such as soil cement, and/or utilizing the "rammed earth" technique (compaction) and lime

It is defined as artificially changing soil properties for construction purposes (by physical or chemical methods) at the natural site. The prime objective of soil stabilization is to improve on-site materials to create a solid and strong sub-base and base courses. In certain regions of the world, typically developing countries and now more frequently in developed countries, soil stabilization is being used to construct the entire road

## 3.2 USES OF STABILIZATION

Pavement design is based on the premise that specified levels of quality will be achieved for each soil layer in the pavement system. Each layer must

- Resist shearing within the layer.
- Avoid excessive elastic deflections that would result in fatigue cracking within the layer or in overlying layers.
- Prevent excessive permanent deformation through densification.

As the quality of a soil layer is increased, the ability of that layer to distribute the load over a greater area is generally increased enough to permit a reduction in the required thickness of the soil and surface layers.

### 3.2.1 Improve Quality

Stabilization is commonly used for better soil gradation, reduction of the PI or swelling potential, and increased durability and strength. Soils stabilized by additives often provide an all-weather working platform for construction operations. These types of soil-quality improvements are referred to as soil modifications.

### 3.2.2 Reduce Thickness

A soil layer's tensile strength and stiffness can be improved by using additives and can thereby reduce the thickness of the stabilized layer and overlying layers within the pavement system. Procedures for designing pavements that use stabilized soils are presented in TM 5-822-5, Chapter 3, and TM 5-825-2, Chapter 2. Before a stabilized layer can be used to reduce the required thickness in the design of a pavement system, the stabilized material must meet the durability requirements of various types of additive stabilization and the minimum strength requirements. Generally, as the percent of fines and the PI increase, pulverization becomes more difficult and it is harder to obtain uniform distribution of the stabilizing additive. For these types of soils, preprocessing or pretreatment with other additives may be necessary. For example, fine-grained soils may be pretreated with lime to aid in their pulverization, making the mixing of a bitumen or cement additive more successful.

The soil-stabilization method is determined by the amount of stabilizing required and the conditions encountered on the project. An accurate soil description and classification are essential for selecting the correct materials and procedure.

## 3.3 METHODS OF STABILIZATION

The two general stabilization methods are mechanical and additive. The effectiveness of stabilization depends on the ability to obtain uniformity in blending the various materials. Mixing in a stationary or traveling plant is preferred. However, other means of mixing (such as scarifiers, plows, disks, graders, and rotary mixers) have been satisfactory.

### 3.3.1 Mechanical

Mechanical stabilization is accomplished by mixing or blending two or more gradations of material to obtain a mixture meeting the required specifications. The blending of these materials may take place at the construction site, at a central plant, or at a borrow area. The blended material is then spread and compacted to the required densities by conventional means. If, after blending these materials, the mixture does not meet the specifications, then stabilization with an additive may be necessary.

### 3.3.2 Additive (Chemical)

Additive refers to a manufactured commercial product that, when added to the soil in the proper quantities, will improve the quality of the soil layer. The two types of additive stabilization discussed mainly in this chapter are chemical and bituminous. Chemical stabilization is achieved by the addition of proper percentages of Portland cement, lime, lime-cement-fly ash (LCF), or combinations of these materials to the soil. Bituminous stabilization is achieved by the addition of proper percentages of bituminous material to the soil. Selecting and determining the percentage of additives depend on the soil classification and the degree of improvement in the soil quality desired. Smaller amounts of additives are usually required to alter soil properties (such as gradation, workability, and plasticity) than to improve the strength and durability sufficiently to permit a thickness-reduction design. After the additive has been mixed with the soil, spreading and compacting are achieved by conventional means.

## 3.4 TYPES OF STABILIZERS WIDLY KNOWN

### 3.4.1 CEMENT

To select the proper stabilizer type for a particular soil, perform a sieve analysis test and An Atterberg - limits test according to the procedures.

Portland cement can be used either to modify and improve the quality of the soil or to transform the soil into a cemented mass with increased strength and durability.

Cement can be used effectively as a stabilizer for a wide range of materials; however, the soil should have a PI less than 30. For coarse-grained soils, the amount passing the No. 4 sieve should be greater than 45 percent. The amount of cement used depends on whether the soil is to be modified or stabilized.

### 3.4.2 LIME

Experience shows that lime will react with many medium-, moderately fine-, and fine-grained soils to produce decreased plasticity, increased workability, reduced swell, and increased strength. Soils classified according to the USCS as CH, CL, MH, ML, OH, OL, SC, SM, GC, GM, SW-SC, SP-SC, SM-SC, GWGC,GP-GC,ML-CL, and GM-GC should be considered as potentially capable of being stabilized with lime. Lime should be considered with all soils having a PI greater than 10 and more than 25 percent of the soil passing the No. 200 sieve.

**Economic Benefits of Lime Stabilization**

- Reduce materials needed for embankment
- Reduction of transport movements in the immediate vicinity of the construction site.
- Machines can move about with far greater ease. Delays due to weather conditions are reduced, leading to improved productivity. As a result, the overall construction duration and costs can be dramatically reduced.
- Structures have a longer service life (embankments, capping layers) and are cheaper to maintain.

### 3.4.3 BITUMINOUS

Most bituminous soil stabilization has been performed with asphalt cement, cutback asphalt, and asphalt emulsions. Soils that can be stabilized effectively with bituminous materials usually contain less than 30 percent passing the No. 200 sieve and have a PI less than 10. Soils classified by the USCS as SW, SP, SW-SM, SP-SM, SW-SC, SP-SC, SM, SC, SM-SC, GW, GP, SW-GM, SP-GM, SW-GC, GP-GC, GM, GC, and GM-GC can be effectively stabilized with bituminous materials, provided the above-mentioned gradation and plasticity requirements are met.

### 3.4.4 COMBINATION

Combination stabilization is specifically defined as lime-cement, lime-asphalt, and LCF stabilization. Combinations of lime and cement are often acceptable expedient stabilizers. Lime can be added to the soil to increase the soil's workability and mixing characteristics as well as to reduce its plasticity.
Cement can then be mixed into the soil to provide rapid strength gain. Combinations of lime and asphalt are often acceptable stabilizers. The lime addition may prevent stripping at the asphalt-aggregate interface and increase the mixture's stability.

### 3.4.5 Fly ash

**Sharma *et al*.** (1992) studied stabilization of expansive soil using mixture of fly ash, gypsum and blast furnace slag. They found that fly ash, gypsum and blast furnace slag in the proportion of 6: 12: 18 decreased the swelling pressure of the soil from 248 kN/m2 to 17 kN/m2 and increased the unconfined compressive strength by 300%.
Srivastava *et al*. (1997) studied the change in micro structure and fabric of expansive soil due to addition of fly ash and lime sludge from SEM photograph and found changes in micro structure and fabric when 16% fly ash and 16% lime sludge were added to expansive soil.
**Srivastava *et al*. (1999)** have also described the results of experiments carried out to study the consolidation and swelling behaviour of expansive soil stabilized with lime sludge and fly ash and the best stabilizing effect was obtained with 16% of fly ash and 16% of lime sludge.
**Cokca (2001)** used up to 25% of Class-C fly ash (18.98 % of CaO) and the treated specimens were cured for 7 days and 28 days. The swelling pressure is found to decrease by 75% after 7 days curing and 79% with 28 days curing at 20% addition of fly ash.

**Pandian *et al*. (2001)** had made an effort to stabilize expansive soil with a class –F Fly ash and found that the fly ash could be an effective additive (about 20%) to improve the CBR of Black cotton soil (about 200%) significantly.

**Turker and Cokca (2004)** used Class C and Class F type fly ash along with sand for stabilization of expansive soil. As expected Class C fly ash was more effective and the free swell decreased with curing period. The best performance was observed with soil , Class C fly ash and sand as 75% , 15% and 10% respectively after 28 days of curing.

**Satyanarayana *et al.* (2004)** studied the combined effect of addition of fly ash and lime on engineering properties of expansive soil and found that the optimum proportions of soil: fly ash: lime should be 70:30:4 for construction of roads and embankments.

**Phani Kumar and Sharma (2004)** observed that plasticity, hydraulic conductivity and swelling properties of the expansive soil fly ash blends decreased and the dry unit weight and strength increased with increase in fly ash content. The resistance to penetration of the blends increased significantly with an increase in fly ash content for given water content. They presented a statistical model to predict the undrained shear strength of the treated soil.

**Baytar (2005)** studied the stabilization of expansive soils using the fly ash and desulpho-gypsum obtained from thermal power plant by 0 to 30 percent. Varied percentage of lime (0 to 8%) was added to the expansive soil-fly ash-desulphogypsum mixture. The treated samples were cured for 7 and 28 days. Swelling percentage decreased and rate of swell increased with increasing stabilizer percentage. Curing resulted in further reduction in swelling percentage and with 25 percent fly ash and 30 percent desulphogypsum additions reduced the swelling percentage to levels comparable to lime stabilization.

**Amu *et al.* (2005)** used cement and fly ash mixture for stabilization of expansive clayey Soil. Three different classes of sample (i) 12% cement, (ii) 9% cement + 3% fly ash and (iii) natural clay soil sample were tested for maximum dry densities (MDD), optimum moisture contents (OMC), California bearing ratio (CBR), unconfined compressive strength (UCS) and the undrained Triaxial tests. The results showed that the soil sample stabilized with a mixture of 9% cement + 3% fly ash is better with respect to MDD, OMC, CBR, and shearing resistance compared to samples stabilized with 12% cement, indicating the importance of fly ash in improving the stabilizing potential of cement on expansive soil.

**Sabat *et al*. (2005)** observed that fly ash-marble powder can improve the engineering properties of expansive soil and the optimum proportion of soil: fly ash: marble powder was 65:20: 15

**Punthutaecha *et al*. (2006)** evaluated class F fly ash, bottom ash, polypropylene fibers, and nylon fibers as potential stabilizers in enhancing volume change properties of sulfate rich expansive subgrade soils from two locations (Dallas and Arlington) in Texas, USA. Ash stabilizers showed improvements in reducing swelling, shrinkage, and plasticity characteristics by 20–80% , whereas fibers treatments resulted in varied improvements. In combined treatments, class F fly ash mixed with nylon fibers was the most effective treatment on both soils. They also discussed the possible mechanisms, recommended stabilizers and their dosages for expansive soil treatments.

**Phanikumar and Rajesh (2006)** discussed experimental study of expansive clay beds stabilized with fly ash columns and fly ash-lime columns. Swelling was observed in clay beds of 100 mm thickness reinforced with 30 mm diameter fly ash columns and fly ash-lime column. Heave decreased effectively with both fly ash and fly ash-lime columns, with, lime-stabilised fly ash yielded better results.

**Wagh (2006)** used fly ash, rock flour and lime separately and also in combination, in different proportion to stabilize black cotton soil from Nagpur Plateau, India. Addition of either rock-flour or fly ash or both together to black cotton soil improve the CBR to some extent and angle of shearing resistance increased with reduced cohesion. However, in addition to rock-flour and fly ash when lime is mixed to black cotton soil CBR value increases considerably with increase in both cohesion and frictional resistance.

**Phani Kumar and Sharma (2007)** studied the effect of fly ash on swelling of a highly plastic expansive clay and compressibility of another non-expansive high plasticity clay. The swell potential and swelling pressure, when determined at constant dry unit weight of the sample (mixture), decreased by nearly 50% and compression index and coefficient of secondary consolidation of both the clays decreased by 40% at 20% fly ash content.

**Kumar *et al*. (2007)** studied the effects of polyester fiber inclusions and lime stabilization on the geotechnical characteristics of fly ash-expansive soil mixtures. Lime and fly ash were added to an expansive soil at ranges of 1–10% and 1–20%, respectively. The samples with optimum proportion of fly ash and lime content (15% fly ash and 8% lime) based on compaction, unconfined compression and split tensile strength, were added with 0, 0.5, 1.0, 1.5, and 2% plain and crimped polyester fibers by weight. The MDD of soil-fly ash-lime mixes decreased with increase in fly ash and lime content. The polyester fibers (0.5–2.0%) had no significant effect on MDD and OMC of fly ash-soil-lime-fiber mixtures. However, the unconfined compressive strength and split tensile strength increased with addition of fibers.

**Buhler *et al*. (2007)** studied the stabilization of expansive soils using lime and Class C fly ash**.** The reduction in linear shrinkage was better with lime stabilization as compared to same % of Class C fly ash.

### 3.4.6 Quarry dust

The quarry dust/ crusher dust obtained during crushing of stone to obtain aggregates causes health hazard in the vicinity and many times considered as an aggregate waste.

**Gupta *et al*. (2002)** made a study on the stabilization of black cotton soil using crusher dust a waste product from Bundelkhand region, India and optimal % of crusher dust(quarry dust) found to be 40%. There was decrease in liquid limit (54.10% to 24.2%), swelling pressure (103.6 kN/m2 to 9.4 kN/m2 ) and increases in shrinkage limit(12.05% to 18.7%), CBR value (1.91 % to 8.06% ), UCS value (28.1 kN/m2 to 30.2 kN/m2 ) with 40% replacement of expansive soil with crusher dust.

**Stalin *et al*. (2004)** made an investigation regarding control of swelling potential of expansive clays using quarry dust and marble powder and observed that LL and swelling pressure decreased with increase in quarry dust or marble powder content.

**Gulsah (2004)** investigated the swelling potential of synthetically prepared expansive soil (kaolinite and bentonite mixture), using aggregate waste (quarry dust), rock powder and lime. Aggregate waste and rock powder were added to the soil at 0 to 25% by weight with lime varying from 0 to 9% by combined weight. There was reduction in the swelling potential and the reduction was increased with increasing percent stabilizers and days of curing.

**Jain and Jain (2006)** studied the effect of addition of stone dust and nylon fiber to Black cotton soil and found that mixing of stone dust by 20% with 3% randomly distributed nylon fibers decreased the swelling pressure by about 48%. The ultimate bearing capacity increased and settlement decreased by inclusion of fiber to stone dust stabilized expansive soil.

### 3.4.7 Rice husk ash

Rice husks are the shells produced during dehusking operation of paddy, which varies from 20% (Mehta 1986) to 23% (Della *et al*. 2002) by weight of the paddy. The rice husk is considered as a waste material and is being generally disposed of by dumping or burning in the boiler for processing paddy. The burning of rice husk generates about 20% of its weight as ash (Mehta 1986). The silica is the main constituent of rice husk ash (RHA) and the quality (% of amorphous and unburnt carbon) depend upon the burning process (Nair *et al*. 2006). The RHA is defined as a pozzolanic material (ASTM C 168 ASTM 1997) due to its high amorphous silica content (Mehta 1986).

**Rajan and Subramanyam (1982)** had studied regarding shear strength and consolidation characteristics of expansive soil stabilized with RHA and lime and observed that RHA contributes to the development of strength as a pozzolanic material when used as a secondary additive along with lime and cement. Under soaked conditions, the soil stabilized with rice husk ash had low strength. The RHA, lime combination also decreased the compression index of stabilized soil.

**Bhasin *et al*. (1988)** made a laboratory study on the stabilization of Black cotton soil as a pavement material using RHA, bagasse ash, fly ash, lime sludge and black sulphite liquor with and without lime. The bagasse ash and black sulphite liquor are found to be not effective as a stabilizing agent. The addition of lime sludge alone to black cotton soil improves the CBR values marginally but reduces the UCS values. Lime sludge in combination with lime improves the strength parameters of black cotton soil sufficiently for its use as a sub-base material. The rice-husk ash causes greater improvement than that caused by fly ash and bagasse ash due to presence of higher % of reactive silica in rice-husk ash in comparison to fly ash and bagasse ash. In conjunction to lime both rice husk ash and fly ash improves the properties of black cotton soil sufficiently meriting its use as a sub-base material.

**Muntohar and Hantoro (2000)** used rice husk ash and lime for stabilization of expansive soil by blending them together. The RHA used were 7.5%, 10% and 12.5% and lime as 2%, 4%, 6%, 8%, 10% and 12% as replacement of expansive soil. Their PI (plasticity index) decreased from 41.25% to 0.96% and swell potential decreased from 19.23% to insignificant with 12-12.5% of RHA-lime mixture. There was also increase in CBR value (3 % to 16 %), internal friction angle (5 0 to 240) and cohesion (54.32 kN/m2 to 157.19 kN/m2), there by increased bearing capacity to 4131 kN/m2 from 391.12 kN/m2

**Chandrasekhar *et al.* (2001)** presented the results of laboratory and field investigations carried out to understand the characteristics of black cotton soil with stabilizing agents like calcium chloride and sodium silicate in comparison with conventional RHA-lime stabilization**.** The RHA-lime stabilization resulted in maximum improvement and strength compared to all other treatment. Calcium chloride treated road stretch showed maximum reduction in ground heave compared to lime, sodium silicate and RHA stabilized stretches, but maximum reduction in shrinkage is observed in lime treated stretch, when additives are used individually. When additives are used in combination, Calcium chloride – sodium silicate treated stretched showed maximum reduction in heave compared to RHA– lime and calcium chloride-RHA stabilized stretches whereas highest reduction in shrinkage is observed in RHA-lime stabilized stretch.

Ramakrishna and Pradeep Kumar (2006) had studied combined effect of rice husk ash (RHA) and cement on engineering properties of black cotton soil. RHA up to 15% in steps of 5% and cement up to 12% in steps of 4% were added. RHA and cement reduced the plasticity of the expansive soil. The dry density of soil increased marginally with increase in

OMC after 4% cement addition. MDD of soil decreased and OMC increased with the increase in the proportion of RHA- cement mixes. The UCS of Black cotton soil increased linearly with cement content up to 8% and at 12%, strength rate reduced. The soaked CBR of the soil was found to be increased with cement and RHA addition. Similar trends to that of UCS were observed with the increase in CBR rate. At 8% cement content, CBR value of soil was 48.57% and with combination of RHA at 5%, 10% and 15%, the values were 54.68%, 60.56% and 56.62%, respectively.

**Sharma *et al*. (2008)** had studied the engineering behavior of a remolded expansive clay blended with lime, calcium chloride and Rice-husk ash. The amount of RHA, lime and calcium chloride were varied from 0 to 16%, 0 to 5% and 0 to 2% respectively by dry weight of soil. The effect of additives on UCS & CBR was found. The stress–strain behavior of expansive clay improved upon the addition of up to 5% lime or 1% calcium chloride. A maximum improvement in failure stress of 225 & 328% was observed at 4% lime & 1% calcium chloride. A RHA content of 12% was found to be the optimum with regard to both UCS & CBR in the presence of either lime or calcium chloride. An optimum content of 4% in the case of lime and 1% in the case of calcium chloride was observed even in clay – RHA mixes.

### 3.4.8 Copper Slag (CS)

Copper slag is produced as a byproduct of metallurgical operations in reverberatory furnaces. It is totally inert material and its physical properties are similar to natural sand.

**Al-Rawas *et al*. (2002)** made an investigation regarding the effectiveness of using cement by-pass dust, copper slag , granulated blast furnace slag, and slag-cement in reducing the swelling potential and plasticity of expansive soils from Al-Khod (a town located in Northern Oman). The soil was mixed with the stabilizers at 3, 6 and 9 % of the dry weight of the soil. The treated samples were subjected to liquid limit, plastic limit, swell percent and swell pressure tests. The study showed that copper slag caused a significant increase in the swelling potential of the treated samples. The study further indicated that cation exchange capacity and the amount of sodium and calcium cations are good indicators of the effectiveness of chemical stabilizers used in soil stabilization.

**Saravan *et al*. (2005)** stabilized the expansive soil using 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80% of dry weight of copper slag. The MDD increased, OMC decreased with increase in CS content and free swell index decreased by 60% corresponding to soil + 70% CS. However, the soaked CBR improved only after addition of 2% of cement and the expansive soil found to be suitable as a sub-grade material by utilizing 50% copper slag waste along with 2% cement.

### 3.4.9 Silica fume (SF)

Silica fume, a co-product from the production of silicon or ferrosilicon metal, is an amorphous silicon dioxide - $SiO_2$ which is generated as a gas in submerged electrical arc furnaces during the reduction of very pure quartz. This gas vapor is condensed in bag house collectors as very fine powder of spherical particles that average 0.1 to 0.3 microns in diameter with a surface area of 17 - 30 $m^2/g$

**Dayakar *et al*. (2003)** conducted laboratory investigation for stabilization of expansive soil using silica fume and tannery sludge with percentage of solid wastes varying from 0, 10, 20, 30, 40, 50, 60- 70%. The addition of wastes did not improve the index properties & maximum dry density but there was gain in strength of the expansive soil with both tannery sludge and silica fume up to 15%.

**El-Aziz *et al*. (2004)** investigated the effect of the engineering properties of clayey soils when blended with lime and Silica Fume (SF). Based on a series of laboratory experiments with lime percentage varying from 1%, 3%, 5%, 7%, 9% and 11% and SF at 5%, 10% and 15%, the plasticity Index and swell potential decreased from 40.25% to 0.98% and from 19.0% to insignificant, respectively, at 11% lime and 15% of SF. There was considerable improvement in CBR value (3.0% to 17.0%), angle of internal friction (60 to 250) and cohesion (55.52 kN/m2 to 157.54 kN/m2). The consolidation settlement was lowered from 0.025 to 0.007m.

**Khare *et al*. (2005)** observed that addition of silica fume and aluminum sludge did not improve the index properties and maximum dry density of the expansive soil, but UCS values increased up to 10%. As the above wastes/ stabilizing agent have cementitious components, curing further increased its UCS value.

**Kalkan and Akbulect (2004)** studied the effect of silica fume on the permeability, swelling pressure and compressive strength of natural clay liners. The test results showed that the compacted clay samples with silica fume exhibit quite low permeability, swelling pressure and significantly high compressive strength as compared to raw clay samples.

### 3.5 Stabilization using other industrial wastes

**Srinivasulu and Rao (1995)** studied the effect of baryte powder as a soil stabilizer and added up to 20% of baryte powder to expansive soil. The PI, OMC and cohesion decreased and MDD, angle of internal friction and CBR values increase with increase in baryite powder and hence can be effectively used for any pavement construction in cohesive soil zones and for rural roads at minimum cost.

Swami (2002) had made the feasibility study for utilization of marble dust in highway sector. The marble dust was added up to 60% by an increment of 15% and found the optimum proportion of expansive soil: marble powder as 75:25. Plasticity Index decreased from 25.1% to 7% with 35% marble dust PI value at 15% and 25% marble powder were observed to be 15.37 %and 8.3% respectively. The dry density increased from 17.56 kN/m3 to 18.34 kN/m3 with 45% marble dust, but CBR value increased (4.59 to 6.81%) upto 25% marble dust and decreased with further increase in marble powder. Mishra and Mathur (2004) studied the stabilization of expansive soil with phosphogypsum (a waste product from phosphoric acid industry) and observed that soil mixed with different proportions of phosphogypsum reduces its liquid and plasticity limit thereby making the soil more workable. The free swell of the soil reduced considerably and the CBR value of the soil increased from 2% to 9 %, when 40% phosphogypsum was added. When the proportion of phosphogypsum was increased beyond 40%, the mix could not be compacted properly.

**Wagh *et al*. (2004)** added sludge‟s from three type of industry textile industry, paper mill and sugar factory, by 10%, 15%, 20% and 25% for improvement in soil properties of expansive soil. With addition of textile industry sludge the free swell index (FSI) decreased and MDD and UCS increased. Adding paper mill sludge UCS increased but decrease in MDD and no considerable effect on FSI. The FSI and MDD decreased and UCS increased with addition of sugar factory sludge.

**Parsons *et al.* (2004)** presented a summary of the performance of a wide range of soils (CH, CL, ML, SM, and SP) treated with cement kiln dust (CKD), to improve the texture, increase strength and reduce swell characteristics. Treatment with cement kiln dust was found to be an effective; strength and stiffness were improved and plasticity and swell potential were substantially reduced. Durability of CKD treated samples in wet-dry testing was comparable to that of soil samples treated with the other additives, while performance was not as good in freeze thaw testing. CKD treated samples performed very well in leaching tests and in many cases showed additional reductions in plasticity and some strength gains after leaching.

**Koyuncu *et al*. (2004)** used three types of ceramic waste, namely, ceramic mud wastes (CMW), crushed ceramic tile wastes (CCTW) and ceramic tile dust wastes (CTDW) for stabilization of expansive soil with Na-bentonite. Swelling pressure and swelling percent of Na-bentonite clay mixed with 40% CCTW decreased 86% and 57%, respectively.

**Al-Rawas (2004)** investigated the physical, engineering, chemical and microfabric characteristics of two soils from Oman treated with incinerator ash produced at Sultan Qaboos University. The soils were mixed with the incinerator ash at 0%, 10%, 15%, 20%, 25% and 30% by dry weight of the soils. The results showed that the incinerator ash used was a non-hazardous waste material. All treated samples showed a reduction in swell percent and cohesion, and an increase in angle of internal friction with the addition of incinerator ash for all curing periods and 20% and 30% additive showed reduction of swell percent of the soils

**Amu *et al.* (2005)** studied the effect of eggshell powder (ESP) on the stabilizing potential of lime on an expansive soil. Based on different engineering tests the optimal percentage of lime-ESP combination was attained at a 4% ESP + 3% lime. But, MDD, CBR value, UCS and undrained triaxial shear strength values indicated that lime stabilization at 7% is better than the combination of 4% ESP + 3% lime.

**Mughieda *et al*. (2005)** studied the feasibility of using composed olive mills solid by product (COMSB), a solid byproduct which causes environmental problems, in stabilization of expansive soil. With addition of COMSB by 2%-8% by weight, the PI, DD and UCS decreased. It was also found that the swell potential was reduced by 56%-65% and the swelling pressure reduced by 56%-72% corresponding to untreated soil. Slow direct shear test indicated that the stabilizing agent decreased the cohesion intercept while the angle of internal friction was increased by 45%-65%.

**Nalbantoglu and Iawfin (2006)** studied the stabilizing effect of Olive cake residue on expansive Soil. Olive cake residue is a by-product after olives have been pressed and olive oil extracted. Olive cake residue was heated up to 550 OC about 1 hour and the ash produced as a result of heating was added into the soil with 3, 5 and 7% by dry weight of soil. With olive cake residue up to 3%, there was reduction in plasticity, volume change, and an increase in unconfined compressive strength, but with further increase in olive cake residue UCS decreased and compressibility increased.
Red mud is a waste material generated by the Bayer Process widely used to produce alumina from bauxite throughout the world. Approximately, 35% to 40% per ton of bauxite treated using the Bayer Process ends up as red mud waste. Kalkan (2006) studied utilization of red mud as a stabilization material for the preparation of clay liners. The test results showed that compacted clay samples containing red mud and cement–red mud additives have a high compressive strength and decreased hydraulic conductivity and swelling percentage as compared to natural clay samples.

**Degirmenci *et al*. (2007)** investigated phosphogypsum with cement and fly ash for soil stabilization. Atterberg limits, standard Proctor compaction and unconfined compressive strength tests were carried out on cement, fly ash and phosphogypsum stabilized soil samples. Treatment with cement, fly ash and phosphogypsum generally reduces the plasticity index with increase in MDD with cement and phosphogypsum contents, but decreased as fly ash content increased. The OMC decreased and UCS increased with addition of cement, fly ash and phosphogypsum.

**Seda *et al*. (2007)** used waste tyre rubber for stabilization of highly expansive clays. The index properties and compaction parameters of the rubber, expansive soil, and expansive soil-rubber (ESR) mixture were determined. While the ESR mixture is more compressible than the untreated soil, both the swell percent and the swelling pressure are significantly reduced by the addition of rubber to the expansive soil. Attom *et al*. (2007) investigated the effect of shredded waste tire on the shear strength, swelling and compressibility properties of the clayey soil from northern part of Jordan. The shredded tires passed US sieve number 4 were added to the soil at 2%, 4%, 6%, and 8% by dry weight of soil. The test results showed that increasing the amount of shredded waste tires increased the shear strength and decrease plasticity index, maximum dry density, permeability, swelling pressure, swell potential and the compression index of the clayey soil.

**Okagbue (2007)** evaluated the potential of wood ash to stabilize clayey soil. Results showed that the geotechnical parameters of clay soil are improved substantially by the addition of wood ash. Plasticity was reduced by 35%, CBR, UCS increased by 23–50% and 49–67%, respectively, depending on the compactive energy used. The highest CBR and strength values were achieved at 10% wood ash.
Peethamparan and Jain (2008) studied four CKD with different chemical and physical characteristics in stabilizing Na-Montmorillonite Clay. All CKDs considerably decreased the plasticity index, thereby improving the workability of the clay, while they also considerably increased the initial pH value of clay, providing a favorable environment for further chemical pozzolanic reaction. The addition of CKDs and subsequent compaction substantially increased the UCS and the stiffness of the clay, thus improving its structural properties. The extent of improvement of the clay characteristics was found to be a function of the chemical composition of the particular CKD, specifically its free lime content. It was also found that the length of curing period after compaction had a major role in the stabilization process

**Cokca *et al*. (2008)** had utilized granulated blast furnace slag (GBFS), and GBFS -Cement (GBFSC) to overcome or to limit the expansion of an artificially prepared expansive soil sample (Sample A). GBFS and GBFSC were added to Sample A in proportions of 5 to 25 percent by weight. Effect of these stabilizers on grain size distribution, Atterberg‟s limits, swelling percentage and rate of swell of soil samples were determined. Effect of curing on swelling percentage and rate of swell of soil samples were also determined. Leachate analysis of GBFS, GBFSC and samples stabilized by 25 percent GBFS and GBFSC was performed. Use of stabilizers successfully decreased the amount of swell while increasing the rate of swell. Curing samples for 7 and 28 days resulted in less swell percentages and higher rate of swell. He had concluded that GBFS and GBFSC should not be used to stabilize expansive soils in regions near to the drinking water wells.
A concise literature review as above is presented in Table 2.1. From the studies of the available literature it is observed that various efforts have been made to study the possible utilization of different industrial wastes for stabilization of expansive soil.

### 3.6 Previous related Studies in Ethiopia

· **Tesfaye, A., (2003)** studied improvement of expansive soil by addition of lime and cement on black cotton soil from different parts of Addis Ababa. Index properties, compaction characteristics and swelling pressure of soil-cement and soil-lime were determined using Atterberg limit test, moisture-density relations, free swell and swelling pressure tests. The conclusions and findings drawn from the study are;

- Expansive soil becomes moderately active to inactive based on the amount of lime and cement added.
- Swelling pressure of expansive soil decreases with increasing lime, cement and molding water content.
- 4-6% of lime and 9-12% of cement yielded significant improvement on plasticity and swelling properties of expansive soils.

· **Nebro, D., (2002)** evaluated lime and liquid stabilizer called Con-Aid for stabilization of potentially expansive subgrade soil on samples collected form Addis-Jimma road which had indicated different pavement damages exacerbated by the presence of expansive soils.
The experimental study involved Atterberg limit test, moisture-density relation, UCS,
CBR and CBR swell. The findings and conclusions of the study can be summarized as follows:

- Addition of lime reduced maximum dry density and increased the optimum moisture content.
- 4% of lime by dry weight of the soil was optimum lime content to stabilize the soil even though increased quantity of lime led to increased strength.
- Addition of lime reduces the swelling potential but no significant improvement in the engineering properties of the soil was attained by addition of Con-Aid.

· **Argu, Y., (2008)** studied stabilization of light grey and red clay subgrade soil collected from Addis Ababa using SA-44/LS-40 chemical and lime. The experimental study involved Atterberg limit, moisture-density relation, swelling pressure and CBR tests. The conclusions and findings drawn from the study are;

- 8% lime yielded significant improvement on plasticity, swelling and strength properties of expansive soils.
- The applications of SA-44/LS-40 chemical alone are ineffective in improving the soaked CBR value of the red clay and light grey soils.
- The application of 0.30lit/m3 of SA-44/LS-40 chemical and 2% lime is an optimum proportion in increasing the soaked CBR value and reducing the swelling pressure of the light grey clay soil.
- The application of 0.08lit/m3 of SA-44/LS-40 chemical and 4% lime

· **Meron, W., (2013)** studied stabilization of sub grade soil collected from Addis Ababa Bole sub city around bole medhanialem using Bagasse ash. The experimental study involved Atterberg limit, moisture-density relation, swelling pressure and CBR tests. The conclusions and findings drawn from the study are;

- The plasticity index slightly reduced with increased in bagasse ash content and curing has also an insignificant effect on the plasticity of the expansive soil.
- The optimum moisture content increased while the maximum dry density values decreased with increment of bagasse ash content.
- Free swell, free swell index and free swell ratio of the stabilized samples decreased with increasing bagasse ash content.
- CBR values slightly increased with the addition of bagasse ash. The change in CBR value is not significant for both cured and uncured samples. Addition of bagasse ash alone does not

improve the strength of soils due to presence of only reactive silica with low amount of calcium content in bagasse ash.

- The plasticity index significantly decreased with addition of bagasse ash combined with lime and increased curing period. However, the addition of bagasse ash alone has a minor effect on the plasticity index of expansive soil.

# CHAPTER FOUR

# WOOD ASH AND BAGAS ASH SOIL STABILIZATION IN ETHIOPIA

## 4.1 Wood Ash as soil stabilizer

Wood ash is a product of combustion from boilers at pulp mills, steam power plants, wood and other thermal power generating facilities, and combustion of wood in fire place. Because wood ash is renewable resource and environmentally friendly material; there is an increased interest in using waste wood for energy production as well. Generally most Ethiopian wood ash produced in the country side that has no electric system.

Expansive soils are considered as undesirable phenomena in geotechnical engineering due to their excessive volume change with seasonal moisture fluctuations. As a type of expansive soils, clay soils suffer from certain problems such as

- high subsidence,
- low shear strength and density
- plasticity properties
- low permeability
- low strength
- changes in pore water pressure,
- volume change and chemical structure

Thus, earthwork researchers and civil engineers have always sought to stabilize clay soils with different additives. Besides, traditional additives are being replaced with waste materials due to their economic advantage, better environmental preservation, and appropriate disposal and reduced adverse effects of disposals. In this regard, wood ash is used as a new waste material additive, wood ash, to stabilize clay soils and to investigate the effect of this additive on Atterberg limits, CBR, compaction, UCS, and free swell of clay soil specimens. Atterberg tests were performed on soil specimens stabilized with different proportions of wood ash.

### 4.1.1 Availability of Wood Ash in Ethiopia

Rural areas in developing countries mainly depend on traditional biomass as fuel. For Ethiopia the main sources are woody biomass (78%), dung (8%), crop residue (7%) and petroleum (5%) (Eshete et al. 2006). High demand for fuel wood and population growth in Ethiopia causes an acute scarcity of wood. Therefore, households are turning to dung and crop residue for energy (Bewket 2003). Improved stoves and alternative cooking methods may decrease consumption of wood. However, wood consumption even increases in villages with good market access while remaining constant in remote villages (Chen et al. 2006).

Wood ash is locally available and financially cheap. Most people of Ethiopia use wood as energy source as a result much amount of wood ash produced from wood combustion in the fire place.

In Ethiopia the major demand for forest products is for fuel wood. It is estimated that about 24 million cubic meters of wood is produced annually, of which 10 % is used for industrial and building purpose and the remainder for fuel wood and charcoal. Estimated consumption demand for fuel wood for energy varies from 49 to 64 million $m^3$. According to Bios Bioenergy system GmbH, infield gasses 21b, A-8010 Graz, Austria; one percent of ash is produced from unit combustion of wood, thus 0.49 to 0.64 million $m^3$ wood ash is produced annually in Ethiopia

### 4.1.2 Environmental Aspects

#### 4.1.2.1 Reduction in Greenhouse effect

The global climate is changing and it is very likely that the change is due to anthropogenic emissions of radioactively active gases, the so-called greenhouse gases, to the atmosphere (IPCC, 2007). Three of the most important greenhouse gases carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) are constantly exchanged between the biosphere and the atmosphere, and any mitigation of further climate change requires the minimization of lime production.

Greenhouse gases emissions in the lime sector result from non-combustion activities (i.e., industrial processes), on-site fossil fuel combustion. As described in the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005, lime manufacture results in non-combustion $CO_2$ emissions. There are three main processes in lime production; stone preparation, Calcination, and hydration. $CO_2$ is emitted during the calcination stage, in which limestone mostly calcium carbonate ($CaCO_3$) is roasted in a kiln at high temperatures to produce CaO and $CO_2$. For the year 2002, The national lime association estimated total greenhouse gases emissions to be 26 MMTCO2E (Million metric tons of carbon dioxide equivalent).[31]

The present (2012) demand for lime is estimated at 6,050 tons, this implies the country Ethiopia contributes the emission of $CO_2$ to the atmosphere. The replacement of lime by wood ash minimizes the emission of $co_2$ because in Ethiopian context more than 80% of the people still use fire wood for preparing their own food. And additional $CO_2$ emitted when producing lime is reduced. But the product of wood ash is continued whether we use wood ash as soil stabilizer or not. Wood ash minimizes the emission of $Co_2$ and $N_2O$ compared to the lime as soil stabilizer.

Wood ash has ability to neutralized soil acidities. If the soil acidity increases, the acid wanted plants will be dried due to the shortage of acid. The relative abundance of nutrients in applied wood ash was Ca > K > Mg > P > N. There was little effect of wood ash on greenhouse effect because the accumulation of $Co_2$ and $N_2O$ is very less compared lime. But wood ash mainly affects the acidity of the soil by increase the pH of the soil.

#### 4.1.2.2 Waste management

Generally there are a lot tones of wood ash produced annually in Ethiopia. This amount of wood ash has been exposed to the environment as the waste product. Therefore waste management should be the big deal to control pollution of the water bodies and to avoid bad smell to the environment. Uncontrolled exposed wastes of wood ash will cause the health effect of humans and animals.

Waste management programs are required to dispose wood ash in a cost-effective and environmentally acceptable. The management of wood ash is an important factor in the environmental and economic analysis of wood burning and to collect the dried area. Effects of seepage from permeable landfill sites which are dangerous to groundwater, the threat of polluting surface water resources particularly small tributaries with low water flow rates and other environmental issues are problems to be solved by effective utilization of the wood ash in the construction industry.

When wood ash seeps to the water body, it causes the water born disease especially in the rural areas. Rural areas population fetch water from the river for drinking purpose but in urban population the water lines will be polluted due to seepage and leakage and also their health affects by bad smelling like TB and other breathing organs diseases. As we discussed above, if we use wood ash to replace lime as soil stabilizer, we can mitigate of all the above problems.

### 4.1.3 Economical Aspect

The use of wood ash as soil stabilizer would provide a new source business, while eliminating previous wood ash to the environment needs money associated with its disposal but when we use wood ash as soil stabilizer, it is possible to minimize the amount of money to avoid the waste product of wood ash. This wood ash also opens the new market for the people especially who lives in rural area are the major users of wood in their day to day activities. This implies wood ash is the one source of money in the rural areas.

Saving the cost by using wood ash as soil stabilizer are nearly always related to the reduction in cement, lime and other stabilizing materials cost. Wood ash, being a waste product, is extremely cheaper than cement, lime and hence offers saving in product cost. Lime is the high-temperature product of the calcinations of limestone. To produce lime there are a lot of stages to get the ordinary limes. It needs time, cost and energy.

### 4.1.4 Previous Studies about wood ash as soil stabilizer

1. Arash Barazesh, Department of Civil Engineering, Arak Branch, Islamic Azad University, Arak, Iran
2. Hamidreza Saba, Amirkabir University of Technology, Tehran, Iran
3. Moustafa Yousefi Rad, Department of Geology, Payam Nour University, Tehran, Iran
4. Mehdi Gharib, Department of Architecture, Aliabad katoul Branch, Islamic Azad University

Studied the effect of wood ash admixture on clay Soils in Atterberg limit test.

The major findings of the study are

**(1) Effect of wood ash on plasticity properties in soil specimens**

The following figures illustrate the results of liquid and plasticity limit experiments on soil specimens with different plasticity indices, which are stabilized with different proportions of wood ash admixture.

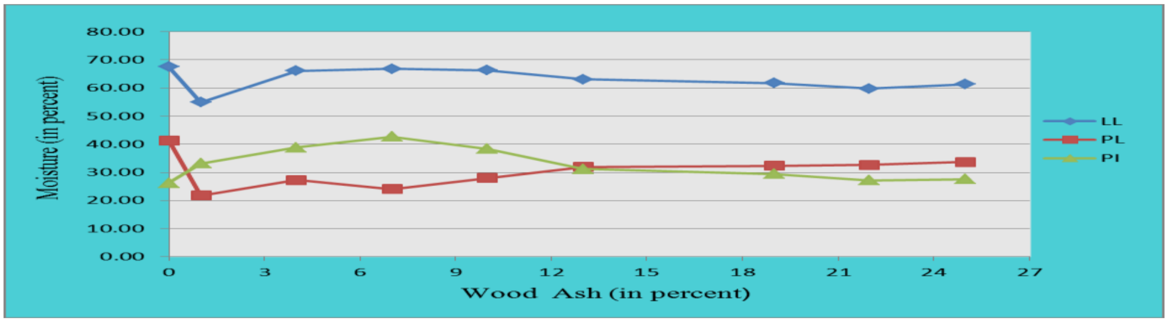


*Fig 4.1 Effect of wood ash on plasticity properties soil with plastic index (PI) of 26*

Soil type 1 with plasticity index of 26 stabilized with different proportions of wood ash

**A)** Adding different proportions of wood ash to soil type 1 reduced the liquid limit in the specimens. The decrease was considerable with 1 percent wood ash in the mixture though it was not intense from 4 to 10 percent wood ash addition. However, the decrease intensified again in the final proportions of the mixture, further reducing the liquid limit.

**B)** Low proportions of wood ash in this type of soil significantly reduced the plasticity limit in the specimens. As the proportion of wood ash increased in the specimen, the reduction in the plasticity index became less intense and almost linear. Thus, the plasticity index in the final proportions of wood ash admixture did not vary considerably comparing with the initial proportions so that the variations were somewhat fixed in the final proportions where a linear trend was observed in the three final proportions.

**C)** Considering the significant decreases in plasticity limit values but slight decreases in the liquid limit, the plasticity index was found to increase in the specimens. The increase in the plasticity index was intense in the initial proportions of wood ash admixture in clay specimens while the variations were moderate in the final proportions. In the intermediate proportions of wood ash in the specimens, the plasticity index had a negative slope with a decreasing trend; however, this trend moderated in the final proportions so that the diagram ended with a linear slope.

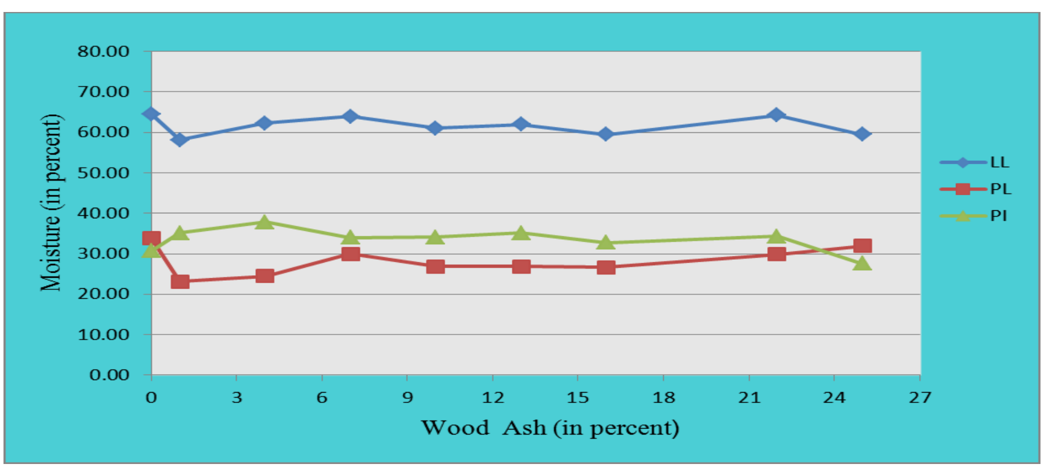


*Fig 4.2 Effect of wood ash on plasticity properties soil with plastic index (PI) of 31*

Soil type 2 with plasticity index of 31 stabilized with different proportions of wood ash

**a)** Adding wood ash in any proportion to this type of soil reduced the liquid limit in the specimens so that the decrease occurred in the initial and final proportions with similar values. However, the decrease was more moderate in the intermediate proportions though the decreasing trend still continued. As shown in the diagram, liquid limit variations in the clay-wood ash mixture were not significant so that the sharpest decrease occurred with 1% wood ash in the mixture, which yielded a 10% reduction in the liquid limit comparing with the initial unmixed soil specimens. However, with other proportions of wood ash in the mixture, the variations remained somewhat within this range.

**b)** Adding wood ash to clay soil reduced plasticity limit in the mixtures comparing with the initial unmixed soil specimens. The decrease was found to be sharpest in the initial and final proportions of wood ash in the mixture while it moderated in the intermediate proportions.

**c)** Considering the experimental results on variations in liquid and plasticity limits, adding wood ash to soil type 2 increased plasticity index in the mixtures in all wood ash proportions except for the 25% wood ash admixture so that the plasticity index reduced in the mixture only in the maximum wood ash proportion. However, the increase in the index became moderate in the intermediate and final proportions so that the diagram took a relatively negative slope.

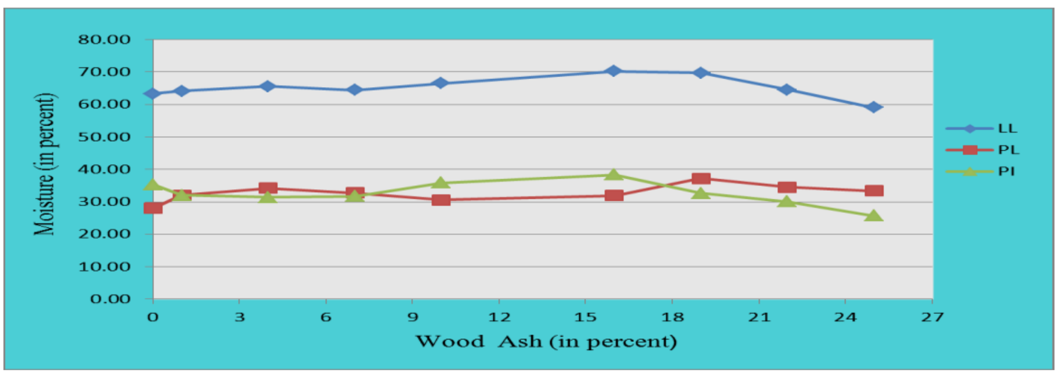


*Fig 4.3 Effect of wood ash on plasticity properties soil with plastic index (PI) of 35*

Soil type 3 with plasticity index of 35 stabilized with different proportions of wood ash

**a)** Adding wood ash to soil type 3 brought about slight increases in the liquid limit in the mixture whereby the increase was more intense in the intermediate proportions of wood ash in the mixture but moderate in the initial and final proportions. With 25% wood ash in the mixture, the liquid limit reduced by 7% in the mixture comparing with the initial admixture proportions.

**b)** Adding wood ash to soil specimens increased plasticity limit in the mixtures so that the increase was somewhat fuzzy in the initial and intermediate admixture proportions but followed a downtrend in the final proportions where the diagram followed a negative slope to the end.

**c)** Adding wood ash to soil type 3 decreased plasticity index in the mixtures so that there occurred a 9% decrease in the plasticity index with 1% wood ash in the mixture and continued with 4% and 9%

wood ash in the mixture. The diagram had a linear slope but started to follow an uptrend in the intermediate wood ash proportions. However, this trend became decreasing in the final proportions so that the plasticity index decreased considerably in the mixture comparing with the unmixed soil specimens. The decrease in the index was more intense with 22% and 25% wood ash in the mixture so that with 25% wood ash in the mixture, the plasticity index reduced as much as 27% holding a value of 25.69.

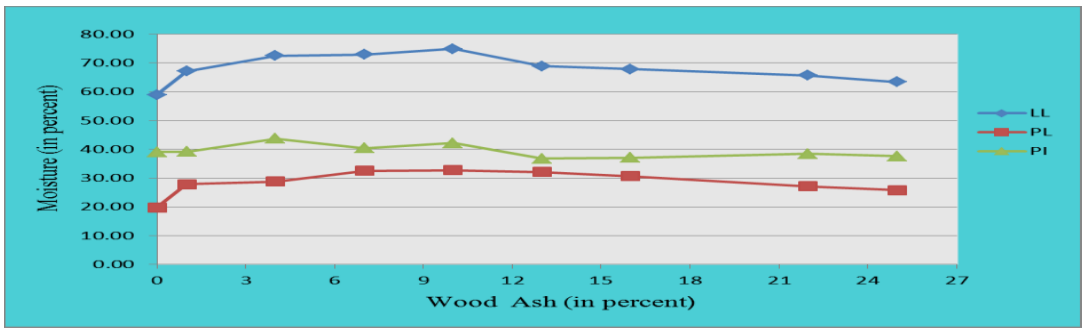


*Fig 4.4 Effect of wood ash on plasticity properties soil with plastic index (PI) of 39*

Soil type 4 with plasticity index of 39 stabilized with different proportions of wood ash

**a)** Adding different proportions of wood ash to soil type 4 increased liquid limit in the mixtures so that the increase was more intense in the initial proportions but less intense in the final proportions where the diagram followed a descending trend.

**b)** Adding wood ash to soil specimens increased plasticity limit in the mixtures comparing with unmixed soil specimens. The increase was more intense in the initial wood ash proportions in the mixture; however, with increased wood ash proportions since 13% and over, the trend reversed so that the diagram followed a downtrend to the end.

**c)** Adding different proportions of wood ash to soil type 4 decreased plastic index in the mixtures, particularly in the intermediate and final proportions. However, the index slightly increased in the initial wood ash proportions in the soil specimens. The general trend of the diagram revealed the reductive effect of wood ash on plasticity index in test specimens.

Concerning the results of experiments on the effect of wood ash on clay soil specimens with primary plasticity indices 26, 31, 35 and 39, they propose following considerations

**(1)** Adding wood ash to soil specimens reduced liquid limit in the mixtures except for soil type 4 in which the diagram followed a downtrend but in the final admixture proportions. Thus, the liquid limit diagram tended to follow a downtrend so that with increased wood ash weight percent in the mixture, there was more decrease in this limit.

**(2)** Adding wood ash to soil types 1 and 2 reduced plasticity index in the mixtures so that different proportions of wood ash in the mixtures decreased this index in the mixtures comparing with the unmixed soil specimens. However, wood ash admixture increased plasticity index in the soil types 3 and 4.

**3)** Adding wood ash to soil specimens reduced the plasticity index in the mixtures so that the diagram followed a downtrend. The decrease was particularly noticeable in soil types 3 and 4.

## 4.2 Wood ash soil stabilization in Ethiopia

The tests conducted include:

- Atterberg limits test
    - Liquid limit
    - Plastic limit
    - Plastic index
- Moisture - density relation test to determine.
    - Optimum moisture content (OMC)
    - Maximum dry density (MDD)
- Free swell tests.
    - Percent of free swell
    - CBR swell for four days soaked.
- California Bearing Ratio (CBR)

| Expected substance that wood ash contains | | Amount |
|---|---|---|
| Moisture % | | 0.4 |
| Organic matter(dry material), % | | 0.68 |
| Ph | | 12.61 |
| Conductivity, Ms | | 10.95 |
| Total content of macro elements (dry matter), % | N | 0.04 |
| | $P_2O_5$ | 0.722 |
| | $K_2O$ | 2.39 |
| | CaO | 52.0 |
| | MgO | 1.32 |
| Content of soluble macro elements(dry matter), mg/100g | N-NO3 | 1.05 |
| | N-NH4 | 0.07 |

| | | |
|---|---|---|
| | $P_2O_5$ | Trace |
| | $K_2O$ | 209 |
| | CaO | 1277 |
| | MgO | Trace |
| Contents of other moving soluble ions (dry matter), mg/Kg | $Cl^-$ | 69 |
| | $SO_4^{2-}$ | 39 |
| | $Na^+$ | 38 |
| Total content of heavy metals (dry matter), mg/Kg | Cd | 1.11 |
| | Pb | 99.7 |
| | Cr | 23.0 |
| | Ni | 16.1 |
| | Cu | 129 |
| | Zn | 133 |
| | As | 11.3 |

*Table 4.1 mineral composition of wood ash.*

### 4.2.1 Soil Sample Property

The test results show that the property of the soil before the addition of wood ash is presented in the Table 4.2 The soil has brownish black colour. It has a liquid limit of 81.84%, plastic limit of 47.01% and plastic index of 34.84%, MDD of 1.33g/cm$^3$, OMC of 35.74%. Liquid limit less than 35% indicates low plasticity, between 35% and 50% intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity (Whitlow, R., 1995).

Therefore, these values indicate the soil is highly plastic clay. Accordingly the soil falls under the A-7-5 soil class based on AASHTO soil classification system. Soils under this class are generally classified as a material of poor engineering property to be used as a sub-grade material. Soils having plasticity index between 20- 55 possess high swelling potential. Therefore the soil sample has high swelling potential. Free swell result of soil sample is 170%.

The soil has a maximum dry density of 1.33g/cm3, optimum moisture content of 35.74%, four days soaked CBR value of 5.32%.

| Property | Quantity |
|---|---|
| Liquid limit (%) | 81.84 |
| Plastic limit (%) | 47.01 |
| Plastic index (%) | 34.84 |
| Optimum moisture content (%) | 35.74 |
| Maximum dry density (g/cm$^3$) | 1.33 |
| 4 days soaked CBR(%) | 5.32 |
| CBR swell (%) | 1.77 |
| Colour | Brownish black |
| Free swell (%) | 170 |

*Table 4.2 Selected geotechnical properties of soil from Ayat.*

*Fig. 4.5 Expansive soil sample*

## 4.2.2 Effect of Wood Ash on Atterberg limits

### *4.2.2.1 Effect of Wood Ash on Liquid Limit*

The following figure (figure 4.3) shows the effect of wood ash on liquid limit for uncured and seven days cured soil sample. As shown in the figure liquid limit is generally decreased with increasing in wood ash percentage. The seven days cured soil sample liquid limit is also decreased in increasing wood ash percentage sample for 5%, 10% and 15%. But after 7 days curing liquid limit of the soil sample is significantly increased. The decrease in liquid limit is observed up to 15% of wood ash content; beyond this amount addition of wood ash increases liquid limit.

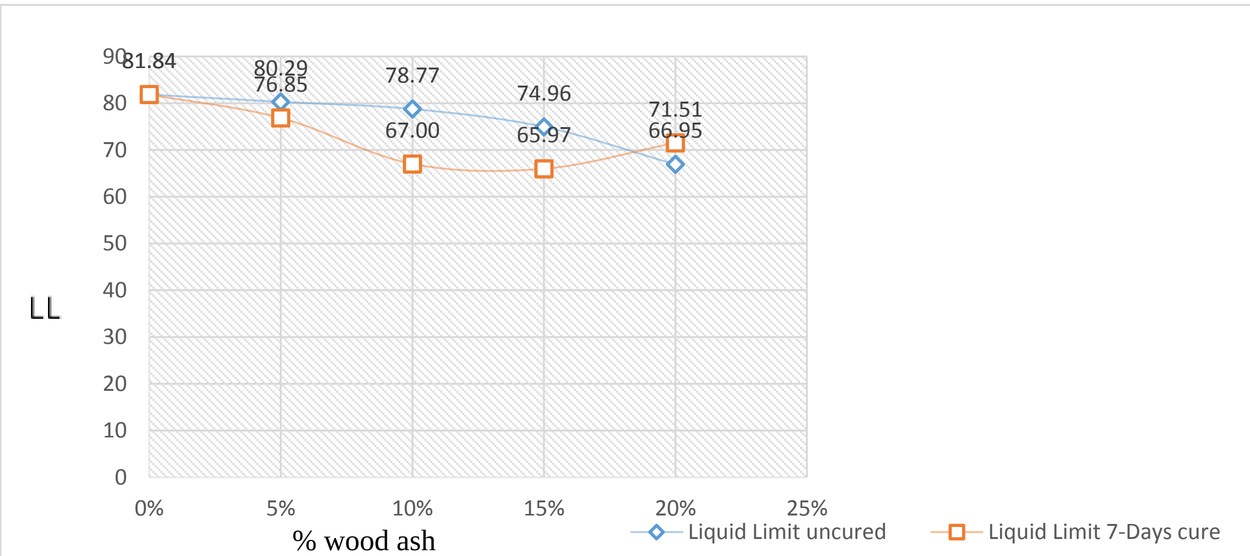


*Fig 4.6: Effect of wood ash on liquid limit of expansive soil*

### *4.2.2.3 Effect of Wood Ash on Plastic Limit*

Figure 4.4 shows the effect of wood ash on plastic limit for uncured and 7 days cured soil sample. As shown in the figure plastic limit is generally increased with increasing in wood ash content up to 10% wood ash for uncured soil sample; beyond this the effect of wood ash decreases plastic limit(for 15% and 20%). The 7 days cured soil sample plastic limit decreases up to 10% wood ash increment and increases at 15% and 20% wood ash.

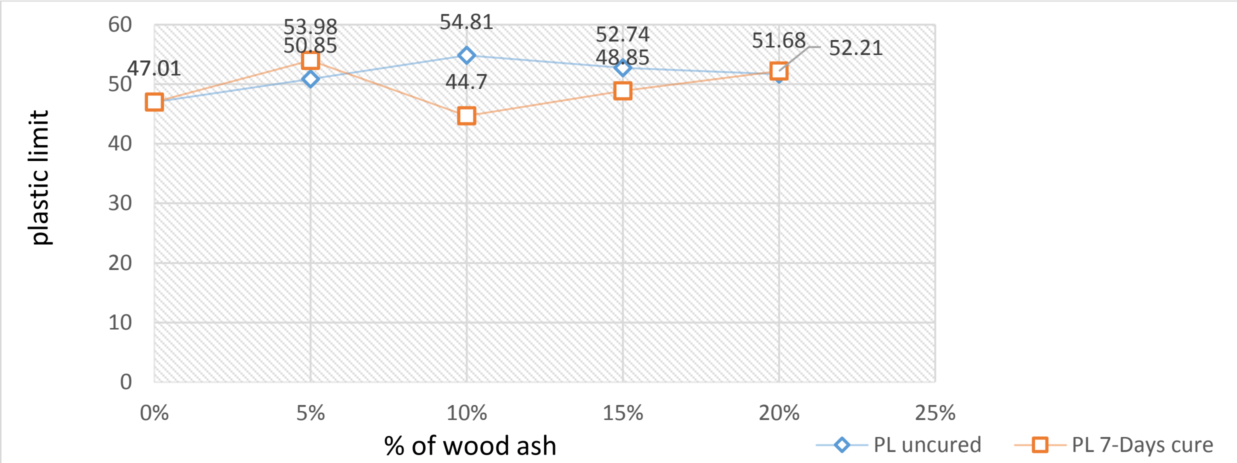


*Fig 4.7: Effect of wood ash on plastic limit of expansive soil*

- Plastic limit of the soil is increased up to 10% and then gradually reduced due to

1). the effect of adsorption is being dominant after 10% of wood ash, reduction in water adsorption.

### 4.2.2.4 Effect of Wood Ash on Plastic Index

Figure 4.5 shows the effect of wood ash on plastic index for uncured and 7 days cured soil sample. As shown in the figure plastic index is generally decreased with increasing in wood ash content for uncured soil sample. The 7 days cured soil sample plastic index decreases with increasing wood ash content up to 15% wood ash. But it increases for 20% wood ash. The effect of curing is observed better as the plastic index of the uncured soil sample plastic index is higher than the 7 days cured soil sample except 20% wood ash.

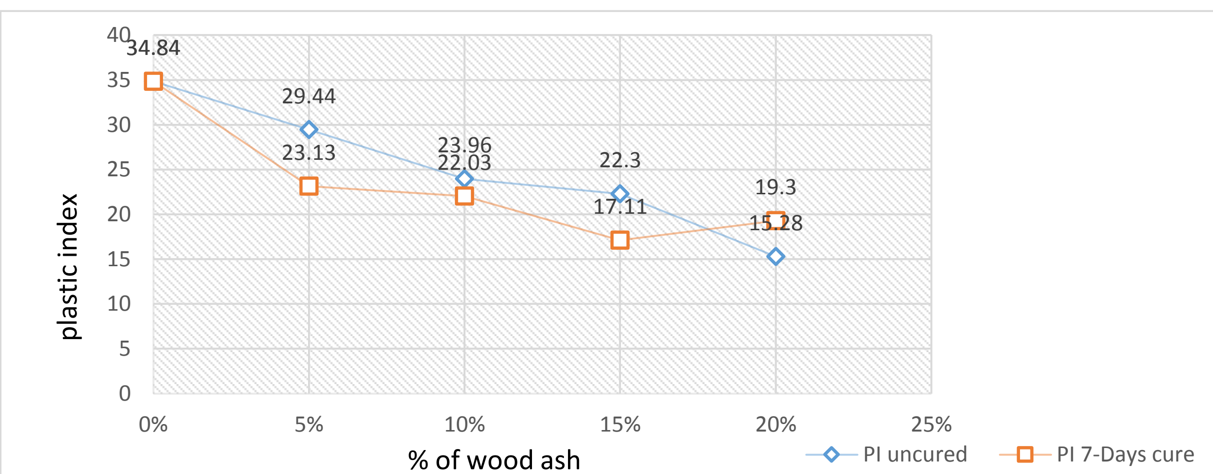


*Fig 4.8: Effect of Wood Ash on plastic index of expansive soil*

- liquid limit and plastic index of sample decreased as wood ash content increased

1). Water absorption of dry expansive soil is higher relative to wood ash

2). Due to reduction of surface contact between soil and water

3). Due to agglomeration which cause in reduction of water absorption

4). Due to formation of adsorbed layer.

5). Due to coating of soil by wood ash particles (no time for pozzolanic reaction)

### *4.2.3 Effect of Wood Ash on Unconfined Compressive Strength*

Figure 4.6 show the effect of wood ash on unconfined compressive strength for uncured and 7 days cured soil sample. As shown in the figure unconfined compressive strength is generally increased with increasing in wood ash content for uncured soil sample up to 15%. After 15% wood ash, stabilizing the soil causes reduction in unconfined compressive strength. The 7 days cured soil sample unconfined compressive strength is generally increased with increasing in wood ash content up to 15%. After 15% wood ash, stabilizing the soil causes reduction in unconfined compressive strength.

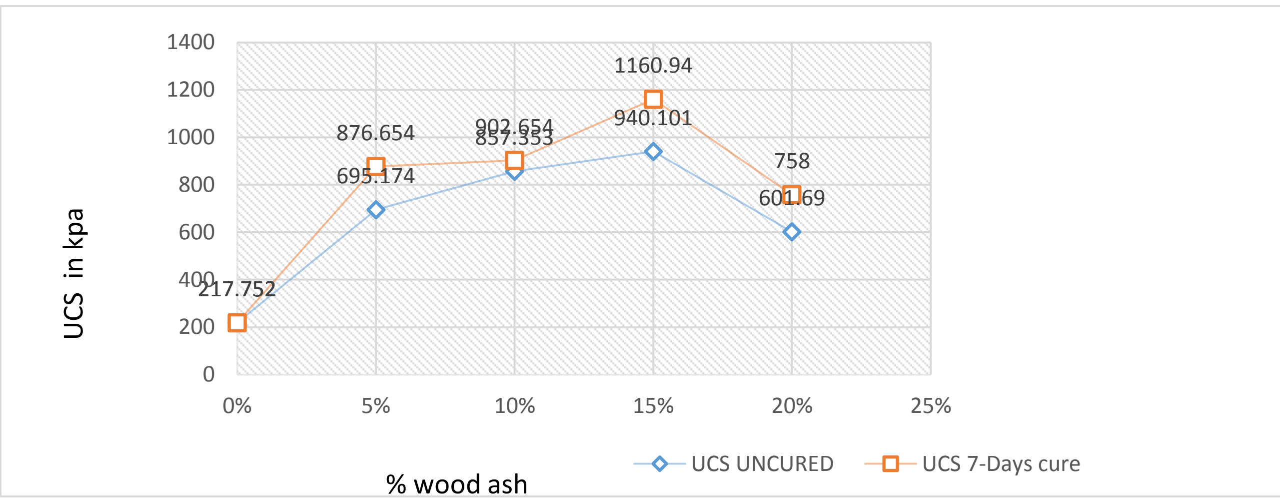


*Fig 4.9: Effect of Wood Ash on Unconfined Compressive Strength for expansive soil*

- UCS of the soil increases gradually up to 15% of wood ash added and decreases due to:

1). Voids are filled by fine wood ash particles which lead to increase in density.

2). Prevention of swelling with the formation of relatively strong bonds between soil and wood ash particles.

3). during agglomeration the radius of wood ash particles which surrounds the soil particle increases resulting loss of bond strength that is why it reduces after 15% of wood ash

### 4.2.4 Effect of Wood Ash on Compaction Characteristics

#### *4.2.4.1 Optimum Moisture Content (OMC)*

The effect of wood ash on optimum moisture content is shown in figure 4.7. As the figure shows OMC reduced with increasing wood ash percentage.

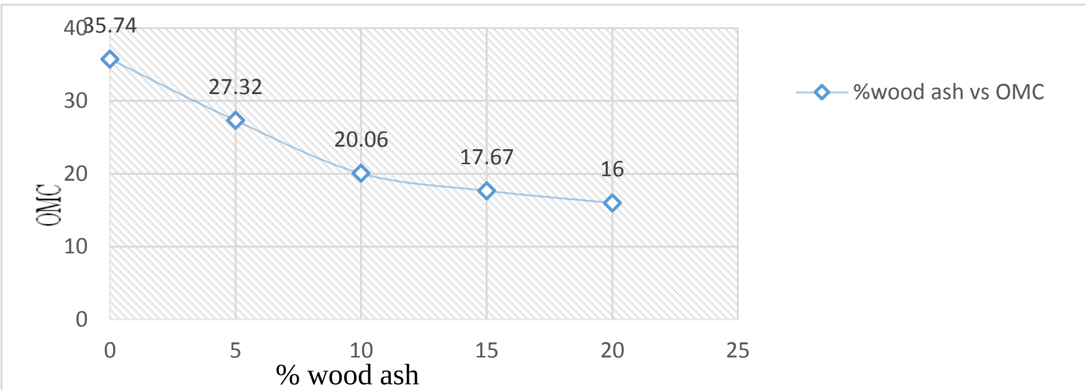


*Fig 4.9.1 effect of wood ash on OMC of expansive soil sample*

- OMC of soil reduced gradually as per the amount of wood ash increases due to

1). Liquid limit of wood ash is much less than soil sample

2). filling of voids with fine wood ash particles

3). Formation of thick layers during adsorption this reduces the amount of water that combines with soil particles.

#### *4.2.4.2 Maximum Dry Density*

The effect of wood ash on maximum dry density is shown in figure 4.8 As the figure shows MDD of soil gradually increase up to 15% wood ash add and reduced when the amount of wood ash add increases.

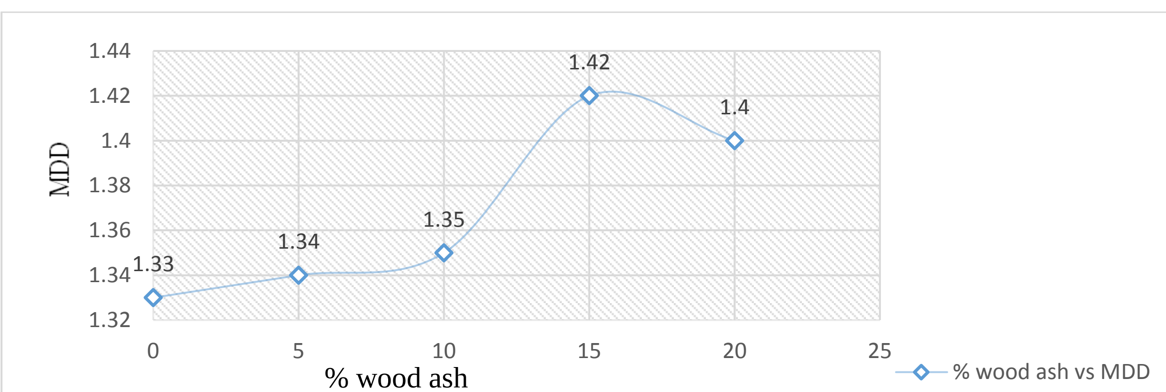


*Fig.4..9.2: Effect of wood ash on MDD of expansive soil sample*

➢ MDD of the soil sample increases gradually up to 15% of wood ash then decreases due to:

1). Reduction of OMC

2). Voids are filled by fine particles of wood ash

3). Disintegration of agglomerated particles due to excessive cations which results repulsive force

## 4.2.5 Effect of wood Ash on Swelling Characteristics

### *4.2.5.1 Free Swell*

The effect of wood ash on the free swell of the expansive soil is shown in the figure 4.9 the reduction in free swell is directly proportional to the percentage of wood ash. The highest reduction in free swell is attained when the expansive soil is treated with 15% wood ash.

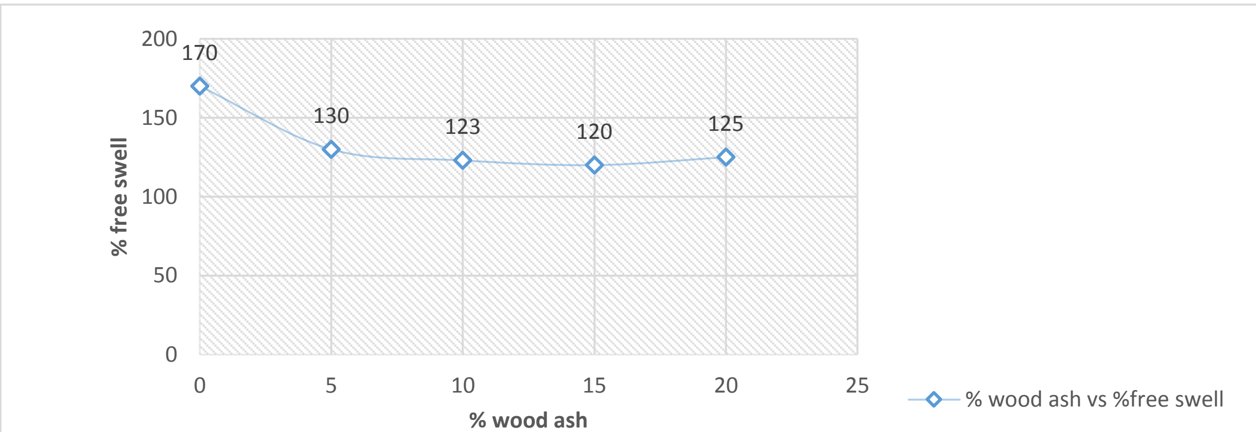


*Figure 4.9.3: Effect of wood ash on free swell of expansive soil sample*

➢ Free swell of the soil sample reduced as per the percentage of wood ash increases due to:

1). the reduction of OMC

### *4.2.5.2 Effect of wood ash on CBR value of the soil sample*

The effect of wood ash on the CBR value of the soil is shown in Figure 4.9.1. The four day soaked CBR value of the soil increases as the percentage of wood ash increases but it reduces at 15% wood ash.

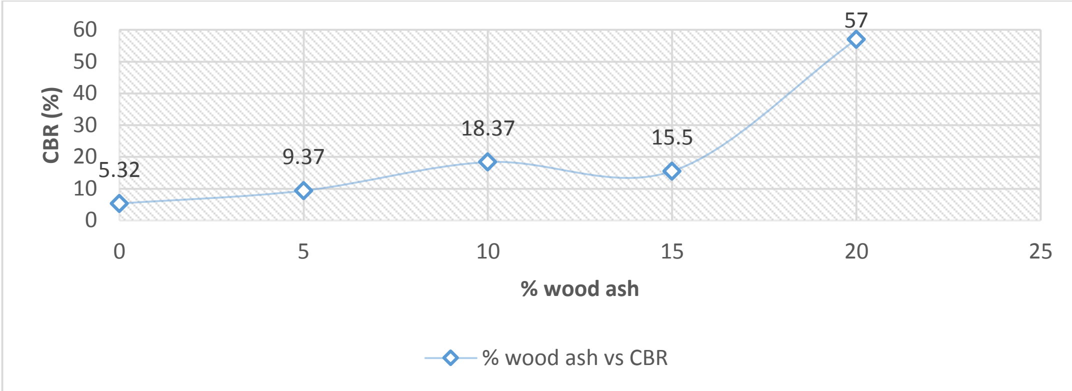


*Figure 4.9.4 effect of wood ash on CBR value of soil sample*

- CBR value of the soil sample increases with increase in wood ash percentage due to:

1). Increase of MDD and reduction in OMC

2). Due to reduction of plasticity and increase of internal bonds after cation exchange

3). soil voids are filled by fine particles of wood ash and compaction is effective

## 4.3 Bagasse Ash as a Soil Stabilizing Material

These days sustainability plays the major role in every aspect of human activities. Many technologies came to end because they were not in harmony with the idea of sustainable development. Sustainability is concerned about the world we will be leaving behind for future generations. It focuses on the social, environmental and economic issues of human activities. Therefore it requires every activity to be environmental friendly, economical and safe for the social.

Bagasse ash contains large amount of silica which is the most important component of cement replacing materials. It is also found in large amount as a byproduct in sugar factories.

Despite this abundance and silica content, relatively little has been done to examine the potential of this material for soil stabilization. Even though little, the conducted researches conform the suitability of this material for soil stabilization as an admixture to lime and cement. But still its suitability as a standalone material is still questionable.

### 4.3.1 Availability of Bagasse ash in Ethiopia

In order to assess the potential of bagasse ash production in Ethiopia, it is imperative to evaluate the sugarcane crop yield in the country. There are three state owned sugar factories functioning in the country in 2013. Their annual production capacity is about 300,000 tons, the sugarcane covering about 10,000 hectares of land. This annual production is not sufficient to the local sugar demand forcing the government to annually import 1.5 million quintals from abroad.

To avoid this shortage of sugar in the country the government plans to establish eight new sugar factories in the coming five years with a total estimated capacity of 2.250 million tons at the start of their production according to the strategic plan and covering about 225,000 hectares.

Beside this the government is undertaking expansion projects on the existing factories to increase their production capacity. At the end of this expansion projects on Fincha, Methara and Wonji-Shoa sugar factories the additional total production capacity is expected to be around 365,000 tons of sugar annually. In detail, Fincha found in the western part of the country planned to increases its production

to 270,000 tons; Wonji-Shoa found 125km east of Addis Ababa plans to increase their production to 350,000 tons; Methara sugar factory found 200kms east of Addis Ababa, is also expected to increase its annual production to
190,000 tons according to the sugar development study paper. Tendaho sugar factory is expected to have an annual production capacity of 600,000 tons is expected to be completed at the end of 2014. As can be seen from the above discussion the sugar production in the country is boosting at a high rate, even planning to hold 2.5% of the world sugar market in the coming years according to the strategic plan. This boosting in sugar production will also result in high amount of bagasse and bagasse ash. Table 4.2 summarizes the expected future sugar production of the country and the respective bagasse ash potential.

| Factory | Expected future production of sugar (tons/year) | Estimated Bagasse (tons/year) | Estimated Bagasse Ash (tons/year) |
|---|---|---|---|
| Wonji-Shoa | 350,000 | 1,050,000 | 84,000 |
| Metehara | 190,000 | 570,000 | 45,600 |
| Fincha'a | 270,000 | 810,000 | 648,000 |
| Tendaho | 600,000 | 1,800,000 | 144,000 |
| New | 2,500,000 | 7,500,000 | 600,000 |
| Total | 3,910,000 | 11,730,000 | 938,000 |

*Table 4.2: Estimated bagasse ash potential of Ethiopia (Hailu, B., 2011)*

The above estimation is based on the targeted annual future sugar production in the country. Sugarcane consist about 30% bagasse, whereas sugar recovered is about 10% of the sugarcane, the bagasse leaves about 8-10% bagasse ash as a waste. As can be seen from the Table 3.5 about 0.94 million tons of bagasse ash is going to be generated annually when the five year strategic plan comes into reality. Currently with sugar production of about 300,000 tons annually, the bagasse ash potential is about 72,000 tons annually

### 4.3.2 Previous Studies

**Gandhi, K. S., (2012)** investigated on stabilization of expansive soil using bagasse ash the experimental study involved Atterberg limit test, free swell index and swelling pressure tests. The findings and conclusions of the study can be summarized as follows:

- The results show that when the percentage of bagasse ash is increases in the soil sample, the plasticity of the soil decreases as shown in Table 4.3.

*Table 4.3 Variations of Atterberg limits with addition of bagasse ash*

| Bagasse ash (%) | LL (%) | PL(%) | PI( %) |
|---|---|---|---|

| | | | |
|---|---|---|---|
| 0 | 72 | 30 | 42 |
| 3 | 67 | 29 | 38 |
| 5 | 63 | 28 | 35 |
| 7 | 58 | 26 | 32 |
| 10 | 52 | 25 | 27 |

- As shown in Figure 4.3 free swell Index decreases as percentage of bagasse ash increases; and shows some linearity between them.

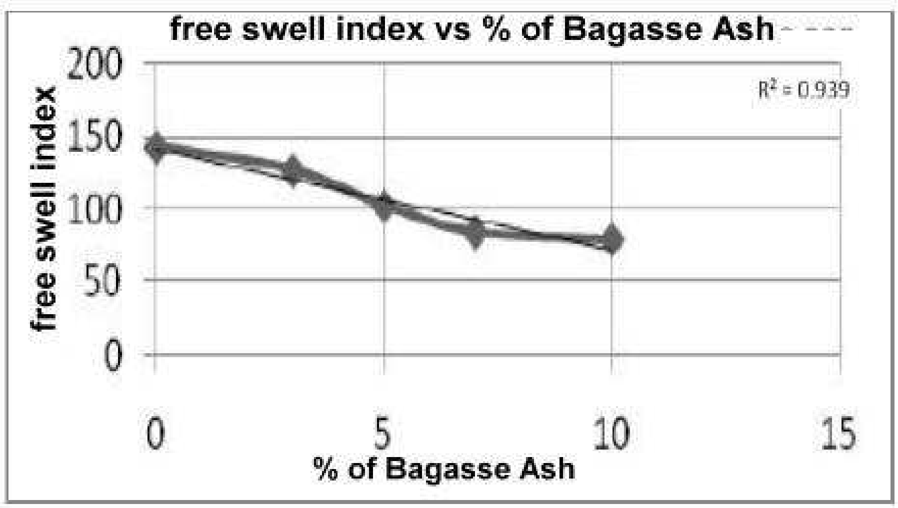


*Fig 4.9.5: Relation between free swell index & percentage of bagasse ash*

- Swelling pressure decreases as percentage of bagasse ash increases. Summary of swelling pressure is shown in Figure 3.3.

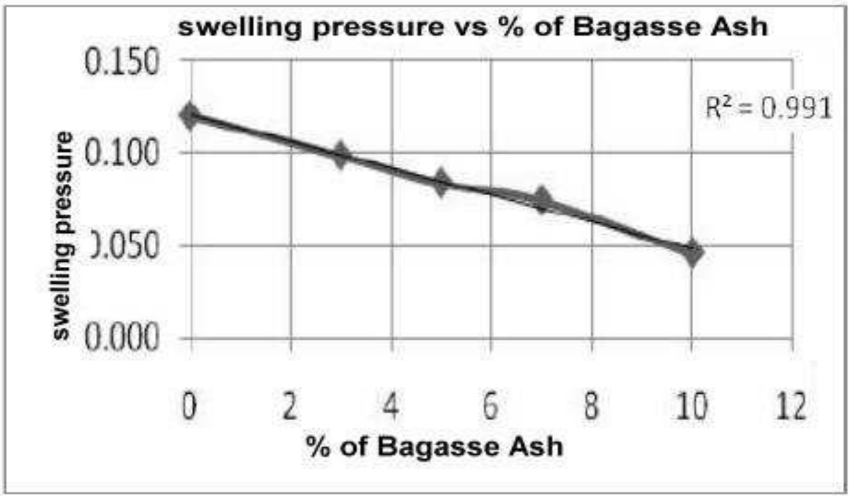


*Fig 4.9.6: Relation between swelling pressure and percentage of bagasse ash*

· **Chittaranjan, M., et al., (2011)** evaluated agricultural wastes as soil stabilizers on clay of medium plasticity. Hence, in their investigation an attempt has been made to utilize certain agricultural wastes such as rise husk ash (RHA), groundnut shell ash (GSA) and sugarcane bagasse ash (SCBA) to stabilize weak subgrade soil. Use of these agricultural wastes improves the subgrade strength of the weak soil. The findings of this study are summarized in Table 4.4

| Agricultural Waste (%) | CBR value For RHA | CBR value for SCBA | CBR value for GSA |
|---|---|---|---|
| 0 | 7.66 | 7.66 | 7.66 |
| 3 | 10.63 | 11.63 | 9.35 |
| 6 | 14.33 | 17.54 | 12.69 |
| 9 | 19.62 | 21.26 | 18.36 |
| 12 | 23.96 | 25.54 | 20.87 |
| 15 | 24.23 | 26.68 | 21.23 |

*Table 4.4: CBR with increase in percentage of bagasse ash*

**Osinubi, K.J., and Thomas, S.A., (2007)** evaluated the influence of compactive efforts on bagasse ash treated black cotton soils. The experimental study involved Atterberg limit test, moisture-density relation, UCS and CBR. The findings and conclusions of the study can be summarized as follows:

- The unconfined compressive strength increased with the addition of bagasse ash content.
- _ The CBR increased with the addition of bagasse ash content. But, these values obtained barely meet the minimum specification by the Nigerian general specification (1997) of 15% CBR for a subgrade material.
- The research concluded that bagasse ash stabilized soil cannot be used as a pavement material. But it can be more profitably used as an admixture with a conventional stabilizer such as cement or lime.

· **Osinubi, K.J., et.al, (2009)** evaluated bagasse ash stabilization of lateritic soil. The experimental study involved moisture-density relation, UCS and CBR. The findings and conclusions of the study can be summarized as follows:

- The MDD and OMC of the treated generally showed trends of decrease and increase, respectively, with higher bagasse ash content as shown in Figure 4.9.4

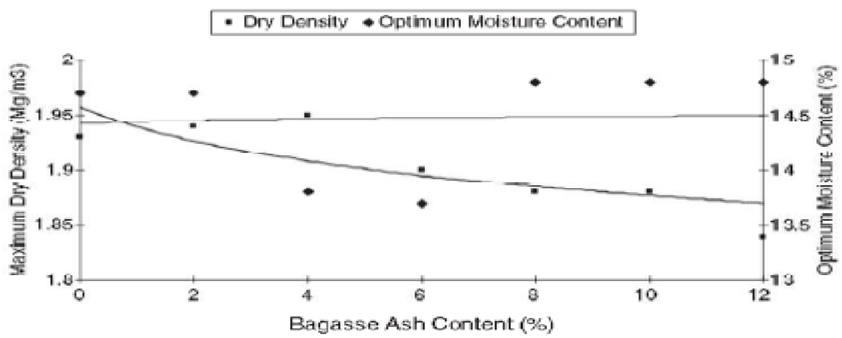


*Fig 4.9.7: Variation of maximum dry density and optimum moisture content with bagasse ash content*

- CBR and UCS values generally increased with the addition of bagasse ash content as shown in Figure 4.9.5 and 4.9.6 respectively.

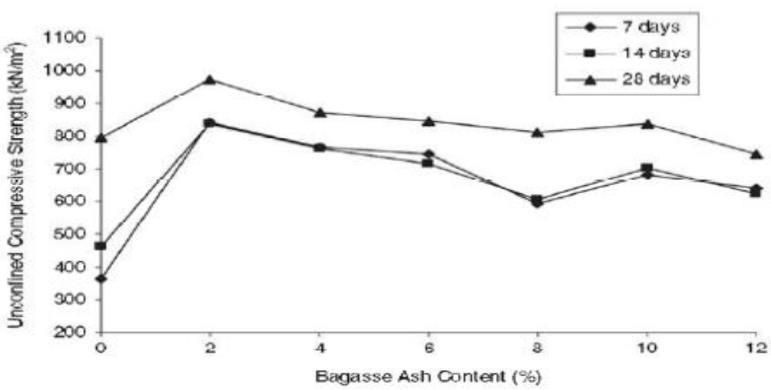


*Fig 4.9.8: Variation of unconfined compressive strength with bagasse ash content*

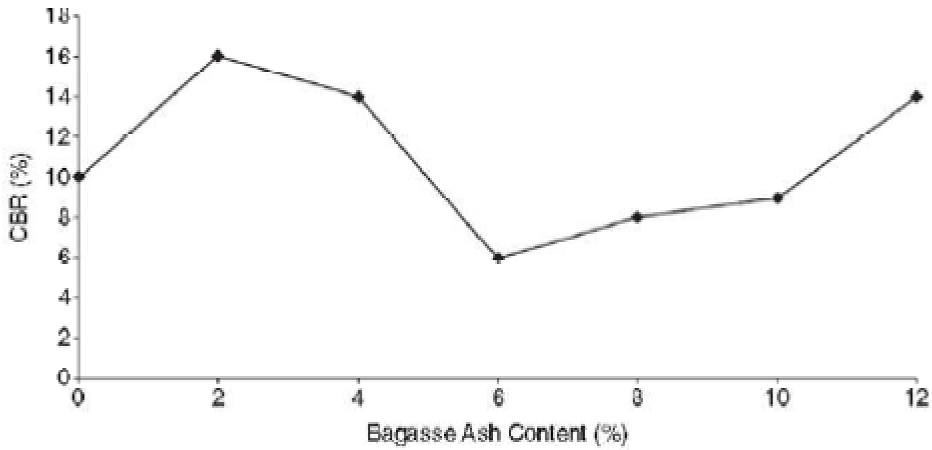


*Fig 4.9.9: Variation of California bearing ratio with bagasse ash content*

- Generally the research concluded that bagasse cannot be used as a standalone stabilizer but should be employed in admixture stabilization.
-

## 4.4 Bagasse Ash soil stabilization in Ethiopia

### 4.4.1 Sample Soil

The Expansive soil sample used for this research work is collected from Addis Ababa, Bole Sub City around Bole Medhanialem church at 8º 59' 38.42''N and 38º 47' 13.09''E from one test pit. The soil is grayish black in color highly plastic clay. A disturbed sample is collected from test pit at a depth below 1.5m in order to avoid the inclusion of organic matter.

| Property | Quantity |
|---|---|
| Percentage passing No. 200 sieve, % | 98.8 |
| Liquid limit, % | 119.5 |
| Plastic limit, % | 41.4 |
| Plasticity index, % | 78.1 |
| AASHTO soil classification | A-7-5 |
| Specific gravity | 2.79 |
| Free swell, % | 210 |
| Free swell index, % | 163.6 |
| Free swell ratio, % | 2.64 |
| Maximum dry density, $g/cm^3$ | 1.26 |
| Optimum moisture content, % | 32.2 |
| Soaked CBR value, % | 0.91 |
| Unsoaked CBR value, % | 15.5 |
| CBR-swell,% | 11.83 |
| Colour | grayish black |

*Table 4.6: Geotechnical properties of the natural soil*

### 4.4.2 Bagasse Ash

Waste bagasse ash as shown in Figure 4.2 was obtained from Wonji sugar factory which is located in the Eastern Ethiopia in Oromiya Regional State. For this research, fresh bagasse ash is taken from the furnace cooled in air by applying a small quantity of water. Then, it is properly packed in sacks and transported to the laboratory

The results of chemical tests carried out on bagasse ash in Ethiopia and elsewhere are shown in Table 4.7 the results indicate pozzolanicity of the bagasse ash. The combined percent composition of silica, Al2O3 and Fe requirement of ASTM C618 standard

| Constituents | % Composition | | |
|---|---|---|---|
| | Addis Ababa* | Nigeria** | India*** |
| $SiO_2$ | 65.58 | 57.12 | 60.98 |
| $Al_2O_3$ | 5.87 | 29.73 | 7.39 |
| $Fe_2O_3$ | 4.32 | 2.75 | 6.07 |
| CaO | 1.78 | 3.23 | 12.66 |
| MgO | 1.23 | - | 2.51 |
| $K_2O$ | 6.41 | 8.72 | 3.53 |
| $Na_2O$ | 1.02 | - | 0.15 |
| $P_2O_5$ | 1.35 | - | 0.61 |
| $SO_3$ | 0.18 | 0.02 | 1.23 |
| $Cl_2$ | < 0.1 | - | - |

*Table 4.7: Oxide composition of bagasse ash*

### 4.4.2 Effect of Bagasse Ash on Atterberg

The effect of bagasse ash on the plasticity index of the soil is shown in Figure 4.9.7 for both uncured and 7 days cured soil samples. As shown in the figure plasticity index generally decreased with increment in bagasse ash content. However, the decrease in plasticity index between cured and uncured samples is insignificant. As seen from the graph, the addition bagasse ash decreases plasticity index of the expansive soil. The decrease is observed to be more with the increase in the quantities of bagasse ash up to 25% and then the trend of decrease is nominal with further increase in the percentages of bagasse ash.

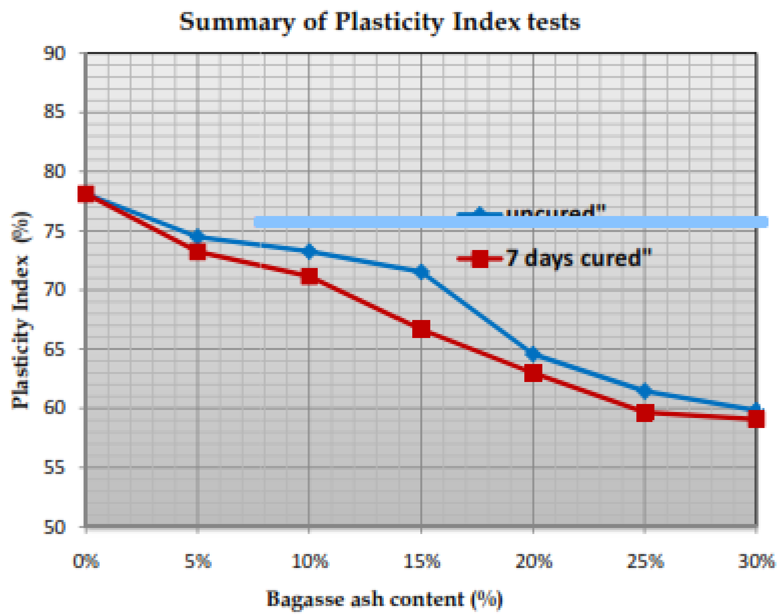


*Fig 4.9.9.1: Variation of plasticity index with addition of different bagasse ash contents*

In general, the plasticity of the soil is decreased by the addition of bagasse ash content. This is clearly shown by the fact that plasticity index of treated soil decreased with increasing additive quantity. These effects are due to the partial replacement with bagasse ash which is non-plastic material and flocculation and agglomeration of clay particles caused by cation exchange may be the other test results.

### 4.4.3 Effect of Bagasse Ash on Swelling Characteristics

#### *4.4.3.1 Free Swell*

The effect of bagasse ash on the free swell of is shown in the figure, the reduction in free swell is directly proportional to the quantity of bagasse ash. The highest reduction in free swell is attained when the expansive soil is treated with 30% bagasse ash which is 162.5% reduction compared to untreated in the figure, the reduction in free swell is directly proportional to the quantity of bagasse ash.

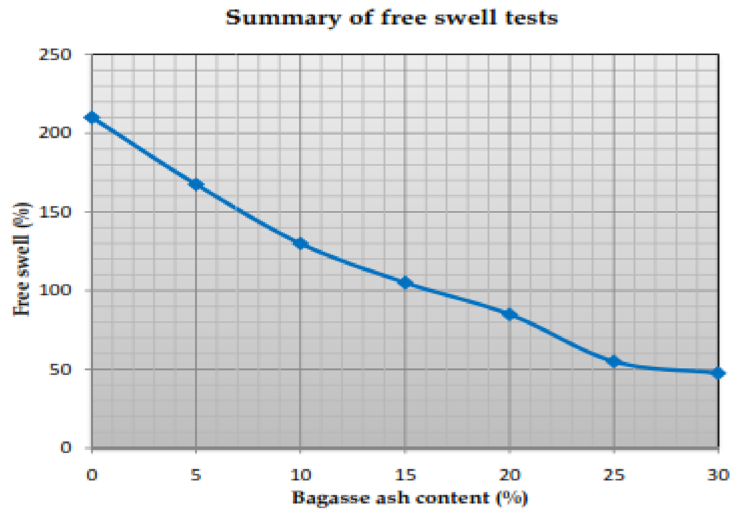


*Fig 4.9.9.2: Changes in the free swell with varying percentage of bagasse ash*

### *4.4.3.2 Free Swell Index*

The effects bagasse ash on the free swell index of the expansive soil is shown in Figure 4.9.9 index value decreased from 176.19% to 17.86% with increased bagasse ash

From the analysis of test results the free swell index of expansive soil is 176.19 to swell classification based on free swell index in Chapter two section 2.4.2.2. Soil has high degree of expansion. As the percentage of bagasse ash increases, the free swell decreases and decreased up to 17.86% at 30% bagasse ash and makes the soil low expansive.

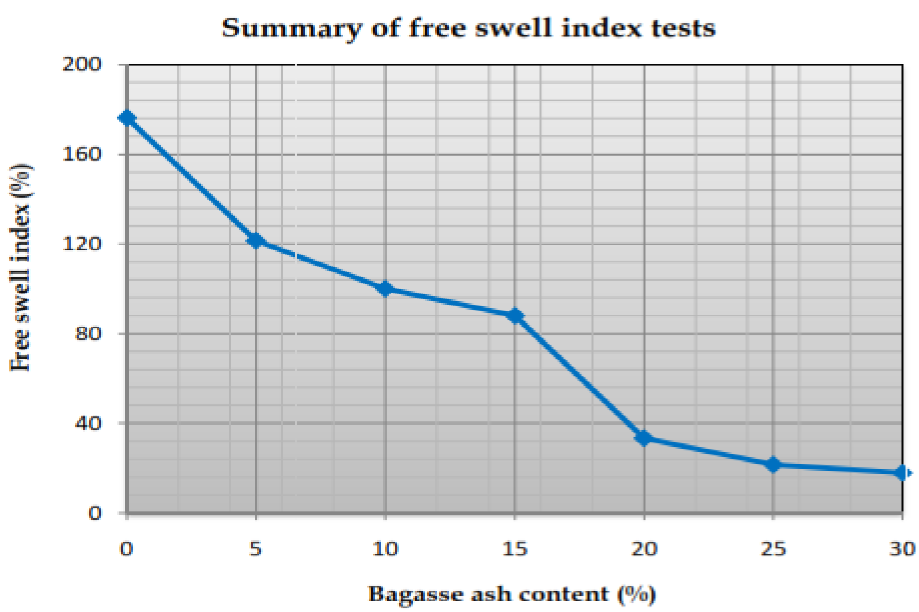


*Fig 4.9.9.3: Changes in the free swell index with varying percentage of bagasse ash*

#### *4.4.3.3 Free Swell Ratio*

As it is shown in Figure 4.9.9.1 when bagasse ash is added to the soil the free swell ratio decreases from 2.76 to 1.2 with increased bagasse ash content from 0 to 30%

From the analysis of test results the free swell ratio of expansive soil is 2.76.

According to swell classification based on free swell ratio the soil is considered as high swelling soil. As the percentage of bagasse ash increases, the free swell ratio value decreased up to 1.2 at 30% bagasse ash and makes the soil low expansive.

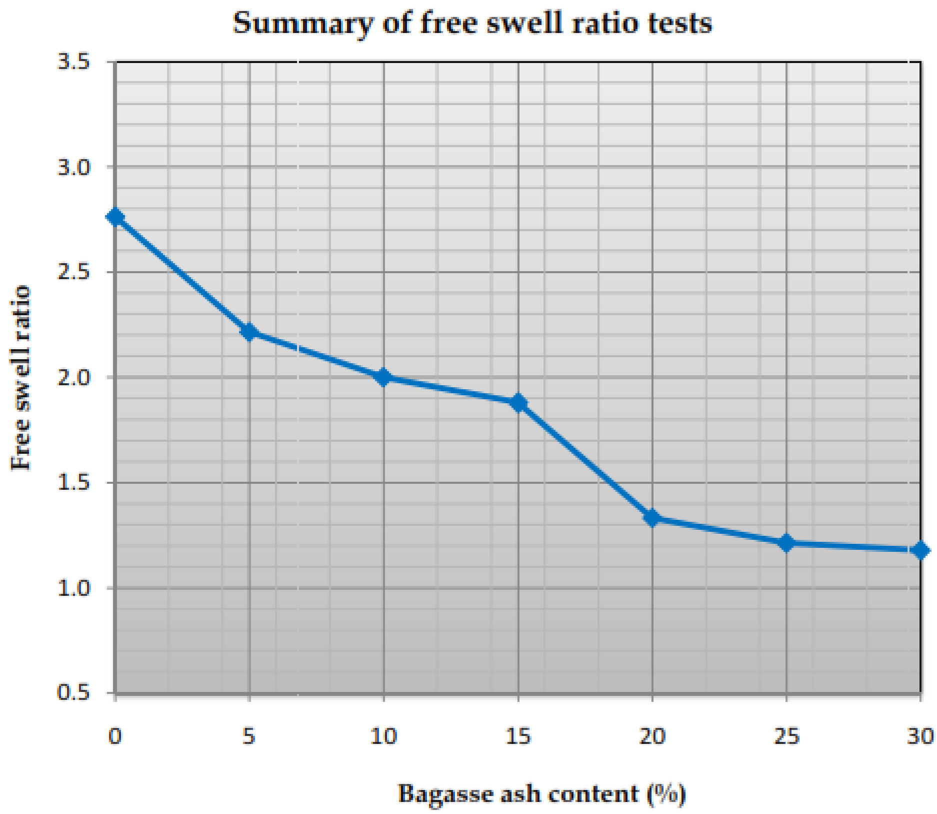


*Fig 4.9.9.4: Effect of addition of bagasse ash on free swell ratio of expansive soil*

From the above three swelling characteristics (free swell, free swell index and free swell ratio) the decrease in swelling are decrease in swelling are mainly due to;

- Bagasse ash decreases swell potential of expansive soils by replacing some of the volume that is previously held by expansive clay minerals and by cementing the soil particles together.

- The reason may be due to cation exchange in the bagasse ash-soil mix.

### 4.4.4 Effect of Bagasse Ash on Specific Gravity

The effect of bagasse ash on the specific gravity of the expansive soil l is shown in Figure 4.9.9.2 Specific gravity decreased from 2.79 to 2.39 with increased bagasse ash content from 0% to 30%. As it is shown in the figure, the reduction in specific gravity is directly proportional to the quantity of bagasse ash.

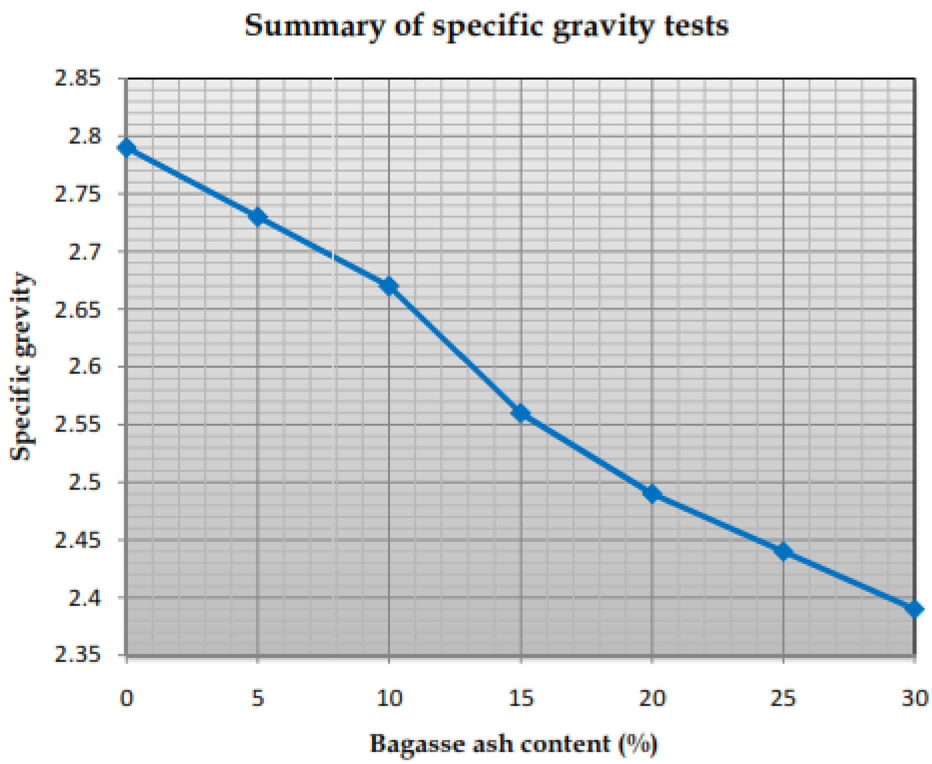


*Fig 4.9.9.5: Variation of specific gravity of soil with bagasse ash content*

This decrease in specific gravity of the soil bagasse ash mix is due to the lower value of specific gravity of bagasse ash.

### 4.4.5 Effect of Bagasse Ash on Compaction Characteristics

#### *4.4.5.1 Maximum Dry Density*

The effect of bagasse ash on the maximum dry density of the
Figure 4.9.9.3 for uncured and 7 days cured soil sample. As shown in the figure, maximum dry density decreases from 1.26g/cm to 0.999g/cm$^3$ for uncured and to 0.918g/cm for 7 days cured soil samples with increased bagasse ash content from 0% to 30%.

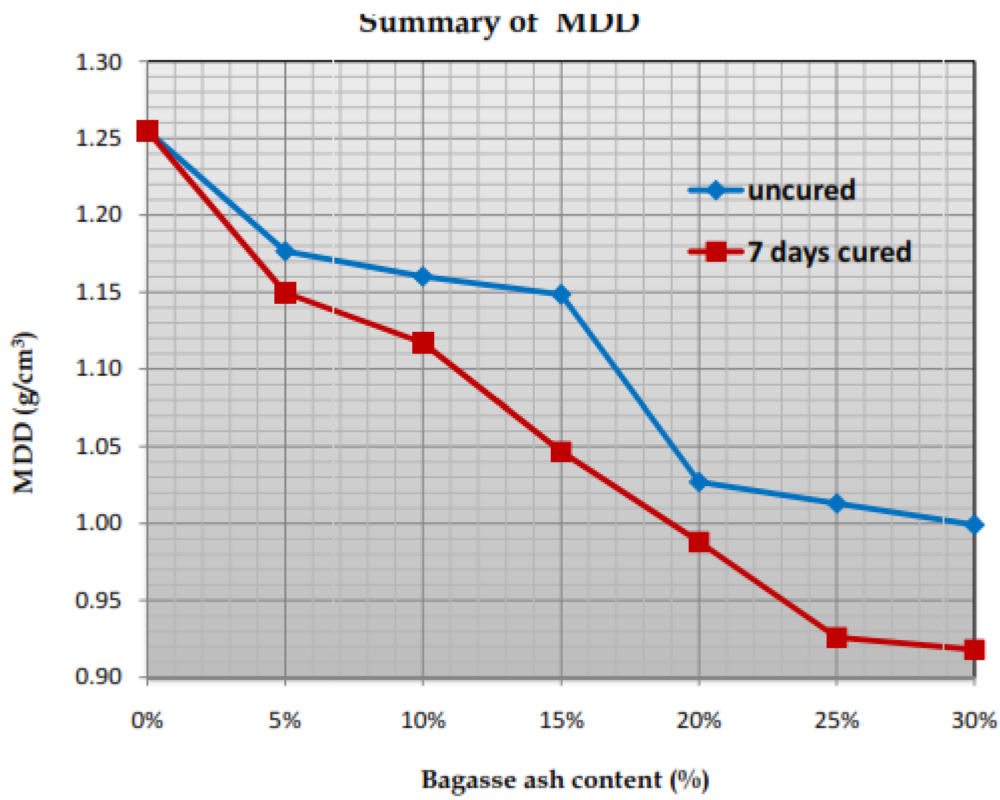


*Fig 4.9.9.6: Variation of MDD with application of different bagasse ash contents*

The decrease in the maximum dry density is mainly due to;

- The partial replacement of comparatively heavy soils with the light weight bagasse ash;
- Comparatively low specific gravity value (1.95) of bagasse ash than that of replaced soil (2.79);
- It may also be attributed to coating of the soil by the bagasse ash which result to large particles with larger voids and hence less density

### *4.4.5.2 Optimum Moisture Content*

The effect of bagasse ash on the optimum moisture content for the soil bagasse ash mix are shown in Figure 4.9.9.4 The optimum moisture content for uncured and 32.24% to 53.78
32.24% to 51.12% for uncured and for 7 days cured soil samples with increased bagasse ash content from 0% to 30%.

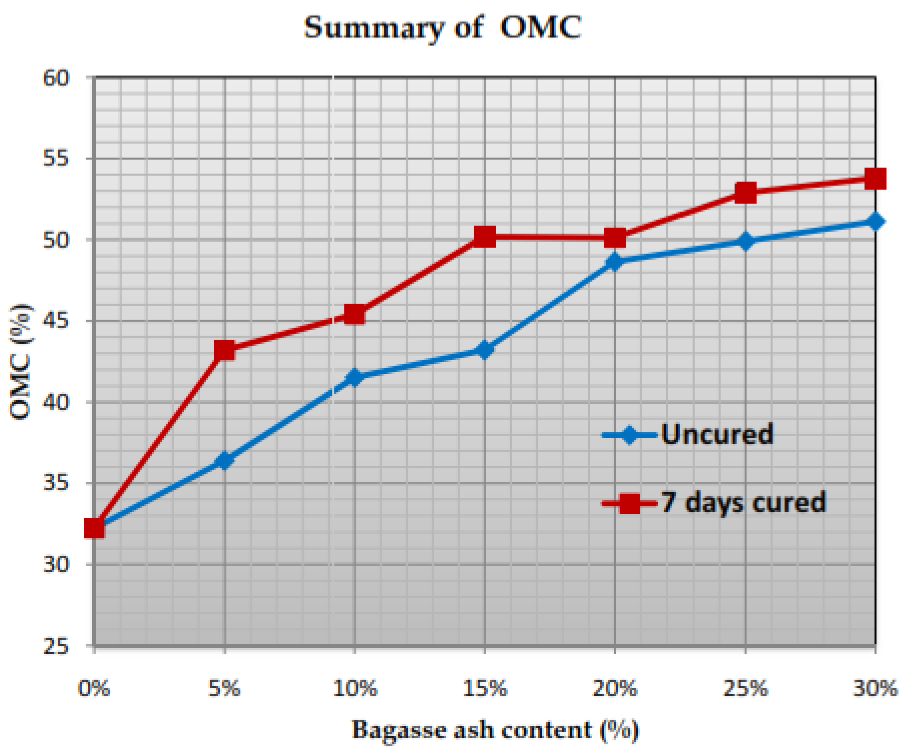


*Fig 4.9.9.7: Variation of OMC with application of different bagasse ash contents*

The increase in the optimum moisture content was mainly due to;

- The optimum moisture content of soil increases with an increase bagasse ash, because bagasse ash is finer than the soil. The more fines the more surface area, so more water is required to provide well lubrication.

- The bagasse ash forms coarser materials, which occupy larger spaces for retaining
- The increase of water content may also be attributed by the pozzolanic reaction of bagasse ash with the soil.

• The increase in OMC due to addition of bagasse ash caused by the absorption of water by bagasse ash. This implies that more water is needed in order to compact the soil with bagasse ash mixture. So bagasse ash effectively dries wet soils and provides an initial rapid strength gain, which is useful during construction in wet, unstable ground conditions. In general it can be utilized in improving the workability of wet soils.

# CHAPTER FIVE

# COMPARISON, CONCLUSION AND RECOMMANDATION

## 5.1 Conclusions

The following conclusions can be drawn from the results of the study.

### 5.1.1 Conclusions on Wood Ash soil stabilization

- The expansive soil used in this study was categorized as an A-7-5 soil class based on the AASHTO soil classification system using the plastic index and liquid limit of the laboratory results. This indicates that the Soils under this class are generally classified as a material of poor engineering property to be used as a sub-grade material and foundation material so the expansive soil is obviously poor material.
- The plasticity index continuously reduced with increased wood ash content and the 7 days curing has also more reducing effect than un cured soil with increasing wood ash content
- The optimum moisture content decreased while the maximum dry density values increased with increment of wood ash content.
- Free swell of the stabilized samples decreased up to 5%, increased at 10%, decreased at 15% and increase at 20% wood ash. The free swell of the black cotton soil fluctuate when the wood ash content increase. The minimum free swell % is at 15% wood ash.
- CBR values are increased with the increasing of wood ash percent. The CBR values for 0%, 5% and 10% wood ash is at 2.54 mm penetration and for the remaining wood ash percentages the CBR values are at 5.08mm penetration depth. The CBR swell is decrease when the wood ash percentage increases.
- Unconfined compressive strength of soil increased with increasing the percentage of wood ash up to 15%, which is maximum at 15% wood ash, and decrease at 20% wood ash. Unconfined compressive strength of the 7 days curing is greater than the uncured soil with respect to increasing of wood ash percentage.
- In this investigation wood ash is used as the expansive soil stabilizer for sub grade and brings significant change. Therefore, wood ash is an effective soil stabilizer material like other stabilizing materials.

### 5.1.4 Conclusions on Bagasse Ash soil stabilization

- The plasticity index slightly reduced with increased in bagasse ash content and curing has also an insignificant effect on the plasticity of the expansive soil.
- The optimum moisture content increased while the maximum dry density values decreased with increment of bagasse ash content.
- Free swell, free swell index and free swell ratio of the stabilized samples decreased with increasing bagasse ash content.
- CBR values slightly increased with the addition of bagasse ash. The change in CBR value is not significant for both cured and uncured samples. Addition of bagasse ash alone does not improve the strength of soils due to presence of only reactive silica with low amount of calcium content in bagasse ash.
- The plasticity index significantly decreased with addition of bagasse ash combined with lime and increased curing period. However, the addition of bagasse ash alone has a minor effect on the plasticity index of expansive soil.

- The addition of lime and bagasse ash together led to a more decrease of the maximum dry density and increase in optimum moisture content compared to the addition of lime and bagasse ash separately.
- The addition of bagasse ash in combination with lime improved the CBR value. The improvement is more significant when the sample is cured. Hence, combination of bagasse ash and lime can strongly improve the strength of the expansive soil.
- Unlike lime in combination with bagasse ash the improvement achieved by bagasse ash alone on the poor geotechnical properties of expansive soil was limited because lower amount of calcium in the bagasse ash. Hence, improvements achieved with up to 30% bagasse ash content were not satisfactory. However, the rate of swelling and heave decreased with increasing bagasse ash content of stabilized expansive soil can be used as a good subgrade material. So, combining two local materials (bagasse ash and lime) can effectively improve the poor geotechnical properties of this soils and help in increasing land resources availability for construction projects and reduce the amount of lime needed for the stabilization purpose.

### 5.1.5 Comparison

According to the results obtained in the study bagasse ash stabilized expansive soil does not bring significant change to use it as a sub-grade material. Therefore, bagasse ash is not an effective standalone stabilizer for highly plastic expansive soils. Bagasse ash plus/in combination with lime can effectively stabilize this soils and combining it with lime or any other stabilizing material raises the cost, availability and environmentally friendliness of the process However, the results obtained using wood ash as soil stabilizer yields better output which makes wood ash best choice because it is cost effective, locally available and environmentally friendly

### 5.1.6 Recommendation

Based on the finding this investigation the following recommendations are stated:

1. Awareness needs be raised about construction practices of chemical stabilization in Ethiopia.
2. There is not enough investigation done on wood ash as soil stabilizer in Ethiopia. So it is recommended that extensive researches on soil samples taken from different places in Ethiopia with different samples of wood ash should be done considering the benefits of the result.
3. Wood ash can be used as a soil stabilizing material, bearing in mind economic and environmental advantage concerned bodies should be aware of this potential soil stabilizing material and promote its level of quality required, collection , production and application.
4. Since wood ash is discovered its usefulness all concerned bodies should make contribution to collect and store properly.

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